INSTITUTION

OF

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1873.

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1873.

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Assistant Secretary.—Alfred Bache,
Institution of Mechanical Engineers,
81 *Newhall Street, Birmingham.*

LIST OF MEMBERS,

WITH YEAR OF ELECTION.

1873.

MEMBERS.

1861. Abel, Charles Denton, 20 Southampton Buildings, London, W.C.
1848. Adams, William Alexander, Walford Manor, near Shrewsbury.
1859. Adamson, Daniel, Newton Moor Iron Works, Hyde, near Manchester.
1871. Adamson, Joseph, West View, Flowery Field, Hyde, near Manchester.
1861. Addenbrooke, George, Messrs. Addenbrookes Smith and Pidcock, Rough Hay Furnaces, Darlaston, near Wednesbury; and Greenhill, Wombourne, near Wolverhampton.
1851. Addison, John, 6 Delahay Street, Westminster, S.W.
1858. Albaret, Auguste, Engine Works, Liancourt-Rantigny, Oise, France.
1870. Alexander, Alfred, Messrs. Alexander and Hoskin, Corinium Iron Works, Cirencester.
1847. Allan, Alexander, Kenilworth Villa, South Cliff, Scarborough.
1865. Allen, William Daniel, Bessemer Steel Works, Sheffield.
1870. Alley, John, Locomotive Superintendent, Moscow and Razan Railway, Moscow.
1865. Alleyne, Sir John Gay Newton, Bart., Butterley Iron Works, Alfreton.
1872. Alliott, James Bingham, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Ilkeston Road, Nottingham.
1871. Allport, Howard Aston, Bestwood Coal and Iron Co., 40 Elm Avenue, Nottingham.
1861. Amos, Charles Edwards, 5 Cedars Road, Clapham Common, London, S.W.
1867. Amos, James Chapman, West Barnet Lodge, Lyonsdown, Barnet.
1856. Anderson, John, LL.D., Superintendent of Machinery to the War Department, Royal Arsenal, Woolwich, S.E.; and 22 Victoria Road, Old Charlton, London, S.E.
1856. Anderson, William, Messrs. Eastons and Anderson, Erith Iron Works, Erith, London, S.E.

1862. Angus, Robert, Locomotive Superintendent, North Staffordshire Railway, Stoke-upon-Trent.

1858. Appleby, Charles Edward, Renishaw Colliery, near Chesterfield.

1867. Appleby, Charles James, Messrs. Appleby Brothers, Emerson Street, Southwark, London, S.E.

1873. Appleby, Henry, Locomotive Superintendent, Monmouthshire Railway, Newport, Monmouthshire.

1859. Armitage, William James, Farnley Iron Works, Leeds.

1866. Armstrong, George, Great Western Railway, Locomotive Department, Stafford Road Works, Wolverhampton.

1863. Armstrong, John, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.

1857. Armstrong, Joseph, Locomotive Superintendent, Great Western Railway, Swindon.

1858. Armstrong, Sir William George, C.B., LL.D., D.C.L., F.R.S., Elswick, Newcastle-on-Tyne; and Cragside, Morpeth.

1870. Armstrong, William Irving, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.

1873. Arnold, David Nelson, Midland Wagon Works, Lander Street, Birmingham.

1857. Ashbury, James Lloyd, 66 Grosvenor Street, London, W.

1873. Ashbury, Thomas, Ashbury Railway Carriage and Iron Works, Openshaw, Manchester.

1870. Atkinson, Charles Fanshawe, Messrs. Marriott and Atkinson, Fitzalan Steel Works, Sheffield.

1869. Austin, William Lawson, Messrs. Austin and Dodson, Cambria Steel and File Works, Sheffield.

1869. Aveling, Thomas, Messrs. Aveling and Porter, Rochester.

1865. Bagshawe, John J., Thames Steel Works, Sheffield.

1865. Bailey, John, Messrs. Courtney Stephens and Co., Blackhall Place Iron Works, Dublin.

1860. Bailey, Samuel, Mining Engineer, The Pleck, near Walsall.

1872. Bailly, Philimond, 49 Rue du Pont Neuf, Brussels.

1866. Baines, William, London Works, Soho, near Birmingham.

1873. Baird, George, Messrs. Baird, Iron Works, St. Petersburg; and 5A Cork Street, Burlington Gardens, London, W.

1866. Baker, Samuel, 22 Oil Street, Liverpool.

1870. Barber, Thomas, Jun., Mining Engineer, High Park Collieries, Eastwood, Nottinghamshire.

1870. Barclay, Arthur, care of Hugh Barclay, Westfield, Surbiton, Kingston-on-Thames.

1860. Barclay, John, Bowling Iron Works, near Bradford, Yorkshire.

1860. Barker, Paul, Old Park Iron Works, Wednesbury.
1866. Barnard, Clement, 4 Billiter Square, London, E.C.
1862. Barrow, Joseph, Whalley Chambers, 88 King Street, Manchester.
1867. Barrows, Thomas Welch, Portable Engine Works, Banbury.
1871. Barry, John Wolfe, 18 Duke Street, Westminster, S.W.
1862. Barton, Edward, Carnforth Hæmatite Iron Works, Carnforth.
1860. Batho, William Fothergill, Melrose House, Erdington, Birmingham.
1872. Bayliss, Thomas Richard, Adderley Park Rolling Mills and Metal Works, Birmingham; and Elm Tree Villa, Smallheath, Birmingham.
1865. Beardshaw, Charles C., Baltic Steel Works, Sheffield.
1869. Beattie, William George, Locomotive and Carriage Superintendent, London and South Western Railway, Nine Elms, London, S.W.
1859. Beck, Edward, Messrs. Neild and Co., Dallam Iron Works, Warrington; and Palmyra Square, Warrington. (*Life Member.*)
1873. Beck, William Henry, 139 Cannon Street, London, E.C.
1864. Beckton, James George, Whitby, Yorkshire.
1865. Bell, Charles, Sunfield House, Old Dover Road, Blackheath, London, S.E.
1858. Bell, Isaac Lowthian, Clarence Felling and Wylam Iron Works, Newcastle-on-Tyne; and The Hall, Washington, County Durham.
1857. Bellhouse, Edward Taylor, Eagle Foundry, Hunt Street, Oxford Street, Manchester.
1868. Belliss, George Edward, Steam Engine and Boiler Works, Ledsam Street, Birmingham.
1854. Bennett, Peter Duckworth, Spon Lane Iron Foundry, Westbromwich.
1872. Bennett, William, Jun., 38 Sir Thomas' Buildings, Liverpool.
1865. Benson, George Henry, Messrs. Freeman Benson and Co., 9 Rumford Street, Liverpool.
1873. Bentley, John Greenwood, Lancashire Steel Works, Gorton, near Manchester.
1861. Bessemer, Henry, 4 Queen Street Place, New Cannon Street, London, E.C.
1866. Bevis, Restel Ratsey, Birkenhead Iron Works, Birkenhead.
1870. Bewlay, Hubert, Birmingham Heath Boiler Works, Spring Hill, Birmingham.
1847. Beyer, Charles F., Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.
1861. Binns, Charles, Mining Engineer, Clay Cross, near Chesterfield.
1866. Birkbeck, John Addison, 8 Acklam Terrace, Newport Road, Middlesbrough.
1847. Birley, Henry, Haigh Foundry, near Wigan.
1870. Blair, John, Chief Locomotive Superintendent, Danish Government Railways, Aarhuus, Denmark.
1862. Blake, Henry Wollaston, F.R.S., Messrs. James Watt and Co., 18 London Street, London, E.C.

1867. Bleckly, John James, Bewsey Iron Works, Warrington; and Daresbury Lodge, near Warrington.

1869. Bloomer, Benjamin Giles, The Sycamores, Pelsall, Walsall.

1862. Blyth, Alfred, Steam Engine Works, Fore Street, Limehouse, London, E.

1863. Boeddinghaus, Julius, Messrs. Heinrich Boeddinghaus and Sons, Elberfeld, Prussia.

1872. Boistel, Georges, 11 Rue de Châteaudun, Paris.

1872. Bolton, Major Frank, 4 Broad Sanctuary, Westminster Abbey, Westminster, S.W.

1869. Borrie, John, Zetland Buildings, Middlesbrough.

1862. Bouch, Thomas, 78 George Street, Edinburgh.

1858. Bouch, William, Shildon Engine Works, Darlington.

1870. Bower, Anthony, Messrs. Forrester and Co., Vauxhall Foundry, Vauxhall Road, Liverpool.

1858. Bower, John Wilkes, Lancashire and Yorkshire Railway, Engineer's Office, Manchester. (*Life Member.*)

1869. Boyd, William, Messrs. Thompson and Boyd, Spring Gardens Engine Works, Newcastle-on-Tyne.

1854. Bragge, William, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield; and Shirle Hill, Sheffield.

1854. Bramwell, Frederick Joseph, F.R.S., 37 Great George Street, Westminster, S.W.

1868. Breeden, Joseph, 157 Cheapside, Birmingham.

1848. Broad, Robert, Horseley Iron Works, near Tipton.

1865. Brock, Walter, Messrs. Denny and Co., Engine Works, Dumbarton.

1852. Brogden, Henry, Sale, near Manchester. (*Life Member.*)

1866. Brown, Andrew Betts, Messrs. Brown Brothers and Co., Rosebank Iron Works, Edinburgh.

1865. Brown, George, Rotherham Iron Works, Rotherham.

1863. Brown, Henry, Waterloo Chambers, Waterloo Street, Birmingham.

1847. Brown, James, Messrs. James Watt and Co., Soho Foundry, near Birmingham.

1853. Brown, Ralph, Patent Shaft Works, Wednesbury.

1869. Browne, Benjamin Chapman, Messrs. Hawthorn and Co., Newcastle-on-Tyne.

1869. Browne, Walter Raleigh, 6 Delahay Street, Westminster, S.W.

1867. Bruce, William Duff, Vice-Chairman, Port Commission, Calcutta.

1873. Brunel, Henry Marc, 18 Duke Street, Westminster, S.W.

1870. Brunlees, James, 5 Victoria Street, Westminster, S.W.

1872. Brunner, Henry, Messrs. John Hutchinson and Co.'s Alkali Works, Widnes; and Cliff House, Appleton, Widnes.

1865. Bryant, Frederick William, Albert Bridge Works, 49 Cheyne Walk, Chelsea, London, S.W.
1866. Bryham, William, Rose Bridge and Douglas Bank Collieries, near Wigan.
1873. Buckley, Robert Burton, Assistant Engineer, Indian Public Works Department, Dehree, Shahabad, India.
1872. Budenberg, Arnold, Messrs. Schaeffer and Budenberg, 23 Lower King Street, Manchester.
1872. Bullock, Thomas, Jun., Messrs. Thomas Bullock and Sons, Button Manufacturers, Cliveland Street Works, Birmingham.
1870. Burgh, Nicholas Proctor, 78 Waterloo Bridge Road, London, S.E.
1858. Burn, Henry, Atlas Iron Works, Litchurch, Derby.
1871. Burrows, James, Wigan.
1870. Bury, William, 5 New London Street, London, E.C.
1873. Bury, William Tarleton, Messrs. Bury and Co., Regent Steel Works, Sheffield.
1856. Butler, Ambrose Edmund, Kirkstall Forge, near Leeds.
1859. Butler, John, Stanningley Iron Works, near Leeds.
1859. Butler, John Octavius, Kirkstall Forge, near Leeds.
1873. Butterfill, Henry Holt, Messrs. Gilbert and Cooper's, Neptune Iron Works, Hull.

1871. Cabry, Charles, District Resident Engineer, North Eastern Railway, York.
1857. Cabry, Joseph, Resident Engineer, Blyth and Tyne Railway, Newcastle-on-Tyne.
1847. Cabry, Thomas, North Eastern Railway, York.
1847. Cammell, Charles, Cyclops Steel and Iron Works, Sheffield.
1864. Campbell, David, 105 Eglinton Street, Glasgow.
1864. Campbell, James, Staveley Coal and Iron Works, Staveley, near Chesterfield.
1869. Campbell, James, Hunslet Engine Works, Leeds.
1860. Carbutt, Edward Hamer, Messrs. Thwaites and Carbutt, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.
1865. Carlton, Samuel, Great Western Railway, Locomotive Department, Swindon.
1869. Carpmael, Frederick, 31 Berners Street, Ipswich.
1866. Carpmael, William, 24 Southampton Buildings, London, W.C.
1872. Carr, Thomas, Richmond Road, Montpelier, Bristol.
1868. Carrington, Thomas, Jun., Mining Engineer, Kiveton Park Colliery, near Sheffield.
1864. Carrington, William Thomas, St. Antholin's Chambers, 26 Budge Row, Cannon Street, London, E.C.

1858. Carson, James Irving, Locomotive Superintendent, West Hartlepool Harbour and Railway, Stockton-on-Tees.

1870. Carver, James, Messrs. Carver and Mosley, Lace-Bobbin and Carriage Works, Butcher Street, Nottingham.

1869. Caspersen, Hans William, Engineer, Danish Government Railway Service; 164 Rye Hill, Newcastle-on-Tyne.

1869. Chadwick, John, Prince's Bridge Iron Works, Water Street, Salford, Manchester.

1871. Chamberlain, Walter, Messrs. Nettlefold's Screw Works, Smethwick, near Birmingham.

1866. Chapman, Henry, 113 Victoria Street, Westminster, S.W.

1872. Chatwin, Thomas, Victoria Works, Berkley Street, Birmingham.

1867. Chatwood, Samuel, Lancashire Safe and Lock Works, Bolton.

1869. Checkley, Thomas, Mining Engineer, Lichfield Street, Walsall.

1873. Cheeseman, William Talbot, Hartlepool Rope Works, Hartlepool.

1857. Chrimes, Richard, Messrs. Guest and Chrimes, Brass Works, Rotherham.

1869. Clapham, Robert Calvert, Earsdon, near Newcastle-on-Tyne.

1866. Claridge, Thomas, Messrs. Claridge North and Co., Phœnix Foundry, near Bilston.

1871. Clark, Christopher Fisher, Mining Engineer, Garswood, near Newton-le-Willows.

1859. Clark, George, Monkwearmouth Engine Works, Sunderland.

1867. Clark, George, Jun., Monkwearmouth Engine Works, Sunderland.

1862. Clark, James, Wellington Foundry, Leeds.

1869. Clark, Thomas, Elswick Marine Engine Works, Newcastle-on-Tyne.

1867. Clark, William, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1869. Clark, William, Mining Engineer, Teversall Collieries, near Mansfield.

1865. Clarke, John, Messrs. Hudswell Clarke and Rodgers, Railway Foundry, Jack Lane, Leeds.

1869. Clarke, William, Messrs. Clarke Watson and Gurney, Victoria Works, South Shore, Gateshead.

1859. Clay, William, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead; and D 7 Exchange Buildings, Liverpool.

1870. Clayton, Nathaniel, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.

1871. Cleminson, James, 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1873. Clench, Frederick, Messrs. Robey and Co., Perseverance Iron Works, Lincoln.

1869. Clerk, Francis North, Mitre Galvanising Works, Bilston Road, Wolverhampton.

1866. Cleworth, Charles, District Locomotive Superintendent, East Indian Railway, Assensole, India.

1867. Cliff, Joseph, Union Foundry, Bradford, Yorkshire.

1847. Clift, John Edward, Redditch Gas Works, Redditch; and Prospect Hill, Redditch.

1858. Cochrane, Charles, Woodside Iron Works, near Dudley; and The Grange, Stourbridge.

1860. Cochrane, Henry, Ormesby Iron Works, Middlesbrough.

1854. Cochrane, John, 3 Hyde Park Gate, London, S.W.

1869. Cochrane, Joseph Bramah, Woodside Iron Works, near Dudley.

1868. Cochrane, William, Mining Engineer, Elswick Colliery, Elswick, Newcastle-on-Tyne; and Oakfield House, Coxlodge, Newcastle-on-Tyne.

1867. Cockey, Francis Christopher, Selwood Iron Works, Frome.

1864. Coddington, William, Ordnance Cotton Mill, Blackburn.

1847. Coke, Richard George, Mining Engineer, Chesterfield.

1867. Coke, William Langton, care of Richard George Coke, Chesterfield.

1848. Corry, Edward, 8 New Broad Street, London, E.C.

1868. Coulson, William, Mining Engineer, Shamrock House, Durham.

1864. Cowans, John, Messrs. Cowans Sheldon and Co., St. Nicholas Iron and Engine Works, Carlisle; and Hartlands, Cranford, near Hounslow.

1870. Cowen, George Roberts, Beck Foundry, Brook Street, Nottingham.

1847. Cowper, Edward Alfred, 6 Great George Street, Westminster, S.W.

1847. Crampton, Thomas Russell, 4 Victoria Street, Westminster, S.W.

1871. Craven, Joseph, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.

1866. Craven, William, Vauxhall Iron Works, Osborne Street, Manchester.

1873. Crippin, Edward Frederic, Mining Engineer, Brynn Hall Colliery, Ashton, near Wigan.

1865. Cross, James, Ditton Lodge, Warrington.

1869. Crossley, Louis J., Dean Clough Carpet Mills, Halifax.

1871. Crossley, William, Furness Iron and Steel Works, Askam, near Dalton-in-Furness, Lancashire.

1863. Crow, George, Messrs. R. Stephenson and Co.'s Works, Newcastle-on-Tyne.

1864. Crowe, Edward, Messrs. Hopkins Gilkes and Co.'s, Tees Engine Works, Middlesbrough.

1864. Daglish, George Heaton, St. Helen's Foundry, St. Helen's.

1869. Daglish, John, Mining Engineer, Tynemouth, near North Shields.

1866. Daniel, Edward Freer, Stapenhill, Burton-on-Trent.

1866. Daniel, William, Messrs. John Fowler and Co.'s Steam Plough and Locomotive Works, Leeds.

1872. Danson, Thomas James, 3 St. Nicholas Buildings, Newcastle-on-Tyne.
1865. Darby, Abraham, Ebbw Vale Iron Works, near Beaufort, Monmouthshire.
1864. Darby, Charles E., Brymbo Iron Works, near Wrexham.
1873. Davey, Henry, Messrs. Hathorn Davis Campbell and Davey, Sun Foundry, Dewsbury Road, Leeds.
1865. Davidson, James, Royal Arsenal, Laboratory Department, Woolwich, S.E.
1868. Davis, Henry Wheeler, Resident Engineer, Great Eastern Railway, Stratford, London, E.
1873. Davis, John Henry, Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester.
1863. Davy, Alfred, Alliance Chambers, George Street, Sheffield.
1873. Davy, David, Messrs. Davy Brothers, Park Iron Works, Sheffield.
1849. Dawes, George, Milton and Elsecar Iron Works, near Barnsley.
1861. Dawson, Benjamin, Engineer, Haswell Colliery, Fence Houses.
1869. Day, St. John Vincent, 166 Buchanan Street, Glasgow.
1868. Dean, William, Great Western Railway, Locomotive Department, Swindon.
1866. Death, Ephraim, Albert Works, Leicester.
1857. De Bergue, Charles, 10 Strand, London, W.C.; and Strangeways Iron Works, Manchester.
1858. Dees, James, Whitehaven.
1858. Dempsey, William, 26 Great George Street, Westminster, S.W.
1872. Denton, John Punshon, Cliff Terrace, East Hartlepool.
1868. Derham, John J., Brookside, near Blackburn.
1865. Dircks, Henry, 48 Charing Cross, London, S.W. (*Life Member.*)
1865. Dobson, Benjamin, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton.
1872. Dobson, Benjamin Alfred, Kay Street Machine Works, Bolton.
1868. Dodman, Alfred, St. James's Works, Lynn.
1873. Donkin, Bryan, Jun., Messrs. B. Donkin and Co., Blue Anchor Road, Bermondsey, London, S.E.
1865. Douglas, Charles P., Consett Iron Works, near Blackhill, County Durham.
1857. Dove, George, Messrs. Cowans Sheldon and Co., St. Nicholas Iron and Engine Works, Carlisle.
1873. Dove, George, Jun., Redbourn Hill Iron and Coal Co.'s Works, Frodingham, Brigg.
1866. Downey, Alfred C., Messrs. Downey and Co., Coatham Iron Works, Middlesbrough; and Royal Exchange, Middlesbrough.
1847. Dübs, Henry, Glasgow Locomotive Works, Glasgow.
1870. Dunlop, James Wilkie, 22 Leadenhall Street, London, E.C.
1857. Dunlop, John Macmillan, Holehird, Windermere.
1864. Dunn, Thomas Edward, Kurhurballee Collieries, Chord Line East Indian Railway, viâ Muddapur Junction, India; (or care of R. Dunn, Howick, Bilton, Northumberland.)

1860. Dyson, George, Saltburn-by-the-Sea.
1865. Dyson, Robert, 14 College Street, Rotherham.

1869. Earnshaw, William Lawrence, Superintending Marine Engineer, South Eastern Railway, Folkestone.
1859. Eassie, Peter Boyd, Messrs. William Eassie and Co., Railway Saw Mills, Gloucester; and 2 Brunswick Villas, Gloucester.
1858. Easton, Edward, Messrs. Easton Amos and Sons, Grove Works, Southwark Street, London, S.E.
1867. Easton, James, Mining Engineer, Nest House, Gateshead.
1856. Eastwood, James, Messrs. Eastwood Swingler and Co., Victoria and Railway Iron Works, Derby.
1868. Eddison, Robert William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.
1871. Edwards, Edgar James, Butterley Iron Works, Alfreton.
1866. Elce, John, Phœnix Iron Works, Jersey Street, Manchester.
1859. Elliot, George, M.P., Houghton-le-Spring, near Fence Houses.
1869. Elliott, Henry Worton, Metal Sheathing Works, 10 Coleshill Street, Birmingham.
1870. Elsdon, Robert, 76 Manor Road, Upper New Cross, London, S.E.
1869. Elwell, Alfred, Edge Tool Works, Wood Green, Wednesbury.
1860. Elwell, Thomas, Messrs. Varrall Elwell and Middleton, 9 Avenue Trudaine, Paris.
1857. Evans, John Campbell, Midland Railway, Locomotive Department, Derby.
1864. Everitt, William Edward, Messrs. Allen Everitt and Sons, Kingston Metal Works, Adderley Street, Birmingham; and Finstal, Bromsgrove.
1865. Evers, Frank, Cradley Iron Works, near Stourbridge.
1869. Eyth, Max, Messrs. John Fowler and Co.'s Steam Plough and Locomotive Works, Leeds.

1869. Faija, Henry, 30 John Street, Bedford Row, London, W.C.
1868. Fairbairn, Sir Andrew, Wellington Foundry, Leeds; and Goldsborough Hall, Knaresborough.
1869. Fairless, John, Forth Banks Engine Works, Newcastle-on-Tyne.
1867. Fardon, Thomas, Linslade Iron Works, Leighton Buzzard.
1865. Faviell, Samuel Clough, Messrs. Taylor Brothers and Co.'s, Clarence Iron Works, Leeds.
1872. Fearn, John Wilmot, Mining Engineer, 31 Devonshire Street, Chesterfield; and Newbold Road, Chesterfield.
1870. Ferguson, Henry Tanner, District Locomotive Superintendent, South Devon, Cornwall and West Cornwall Railways, Carn Brea Works, Redruth.

1854. Fernie, John, Bonchurch, Ventnor, Isle of Wight.

1866. Fiddes, Walter, Engineer, Bristol United Gas Works, Bristol.

1872. Fidler, Edward, Platt Lane Colliery, Wigan.

1867. Field, Edward, Chandos Chambers, Buckingham Street, Adelphi, London, W.C.

1861. Field, Joshua, 110 Westminster Bridge Road, Lambeth, London, S.E.

1865. Filliter, Edward, Resident Engineer, Leeds Water Works, 16 East Parade, Leeds.

1868. Firth, Arthur, Leeds Iron Works, Leeds.

1868. Firth, Samuel, 30 Springfield Mount, Leeds.

1871. Fisher, Benjamin Samuel, Locomotive Superintendent, Somerset and Dorset Railway, Highbridge, near Bridgewater.

1864. Fleet, Thomas, Crown Boiler Works, Westbromwich.

1847. Fletcher, Edward, Locomotive Superintendent, North Eastern Railway, Gateshead.

1858. Fletcher, Henry Allason, Messrs. Fletcher Jennings and Co., Lowca Engine Works, Whitehaven. (*Life Member.*)

1872. Fletcher, Herbert, Ladyshore Colliery, Little Lever, Bolton; and The Hollins, Bolton.

1857. Fletcher, James, Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.

1866. Fletcher, James, Jun., Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.

1867. Fletcher, Lavington Evans, Chief Engineer, Association for the Prevention of Steam Boiler Explosions, 41 Corporation Street, Manchester.

1872. Flower, James J. A., Messrs. James Flower and Sons, Cape Town, Cape of Good Hope; and 9 America Square, Crutched Friars, London, E.C.

1859. Fogg, Robert, 17 Park Street, Westminster, S.W.

1871. Forrest, William John, Assistant Engineer, Intercolonial Railway, Ottawa, Canada.

1861. Forster, Edward, Spon Lane Glass Works, near Birmingham.

1869. Forster, George Baker, Backworth, Newcastle-on-Tyne.

1849. Forsyth, John C., North Staffordshire Railway, Stoke-upon-Trent.

1861. Foster, Sampson Lloyd, Old Park Hall, Walsall.

1866. Fowler, George, Mining Engineer, Basford Hall, near Nottingham.

1847. Fowler, John, 2 Queen Square Place, Westminster, S.W.

1866. Fox, Charles Douglas, 6 Delahay Street, Westminster, S.W.

1859. Fraser, John, 18 York Place, Leeds.

1870. Freeman, George Frederick, Broughton Copper Works, Broughton Road, Manchester.

1852. Froude, William, F.R.S., Chelston Cross, Torquay.

1866. Fry, Albert, Bristol Wagon Works, Temple Gate, Bristol.

1866. Galloway, Charles John, Knott Mill Iron Works, Manchester.

1862. Galton, Capt. Douglas, C.B., R.E., F.R.S., Director of Works and Public Buildings, 12 Whitehall Place, London, S.W.; and 12 Chester Street, Grosvenor Place, London, S.W.

1870. Garstang, James H., Bridgewater Engineering Co.'s Works, Bridgewater.

1867. Gauntlett, William Henry, 9 Grange Road, Middlesbrough.

1871. Gibbins, Richard Cadbury, Berkley Street, Birmingham.

1848. Gibbons, Benjamin, The Leasowes, near Birmingham.

1870. Gibson, John, Engineer, Ryhope Colliery, near Sunderland.

1872. Gilbert, Ebenezer Edwin, Canada Engine Works, Montreal, Canada.

1856. Gilkes, Edgar, Messrs. Hopkins Gilkes and Co., Tees Engine Works, Middlesbrough.

1866. Gilroy, George, Engineer, Ince Hall Colliery, Wigan.

1862. Godfrey, Samuel, Messrs. Bolckow Vaughan and Co.'s Iron Works, Middlesbrough.

1869. Goodeve, Thomas Minchin, Goldsmith Buildings, Temple, London, E.C.

1865. Göransson, Göran Fredrick, Steel Works, Gefle and Hägbo, Sweden.

1871. Gowenlock, Alfred Hargreaves, care of Messrs. Jessop and Co., Railway Contractors, 93 Clive Street, Calcutta.

1869. Grainger, James Nixon, Public Works Department, Chepank, Madras.

1865. Gray, John McFarlane, Board of Trade Steam Ship Surveyor, St. Katherine's Dock House, London, E.

1870. Gray, Matthew, 106 Cannon Street, London, E.C.; and Silvertown Telegraph Works, North Woolwich, E.

1870. Greaves, James Henry, Albert Buildings, Queen Victoria Street, London, E.C.

1861. Green, Edward, Jun., Phœnix Works, Wakefield.

1871. Greener, John Henry, 84 Lombard Street, London, E.C.

1858. Greenwood, Thomas, Albion Works, Armley Road, Leeds.

1865. Greig, David, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1866. Grice, Edwin James, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1860. Grice, Frederic Groom, Ansty's Lea, Torquay.

1868. Grierson, Henry Houldsworth, Messrs. Ormerod Grierson and Co., St. George's Iron Works, Hulme, Manchester.

1871. Grover, Captain George Edward, R.E., Cecil House, Bengeo, near Hertford.

1870. Guilford, Francis Leaver, Messrs. Cowen and Co., Beck Foundry, Brook Street, Nottingham.

1866. Gurden, Charles Frederick, Superintendent Engineer, Brazil and River Plate Steam Boat Co., 43 Canning Street, Birkenhead.

1870. Gwynne, James Eglinton Anderson, Essex Street Works, Strand, London, W.C. (*Life Member.*)

1870. Gwynne, John, Hammersmith Iron Works, Hammersmith, London, W.

1863. Hackney, William, Landore Steel Works, Swansea.

1861. Haggie, Peter, Hemp and Wire Rope Works, Gateshead.

1863. Hall, Joseph, Graz Iron Works, Graz, Styria, Austria.

1871. Hall, William Silver, Abbey Works, Nuneaton.

1871. Halpin, Druitt, 61 Cambridge Road, Hammersmith, London, W.

1870. Hamand, Arthur Samuel, Stephenson Chambers, New Street, Birmingham.

1869. Hambling, Thomas Crump, 7 Westminster Chambers, Victoria Street, Westminster, S.W.

1860. Hamilton, Gilbert, Messrs. James Watt and Co., Soho Foundry, near Birmingham ; and Leicester House, Kenilworth Road, Leamington.

1870. Hannah, Joseph Edward, Consett Water Works, Waskerley, Darlington.

1870. Harding, George Edward, 52 Broadway, New York.

1869. Harfield, William Horatio, Mansion House Buildings, Queen Victoria Street, London, E.C.

1873. Harman, Harry Jones, Engineer, Duke of Sutherland's Colliery, Brora, Sutherland.

1859. Harman, Henry William, Canal Street Works, Manchester.

1873. Harris, Richard Henry, Messrs. Fletcher Jennings and Co.'s., Lowca Engine Works, Whitehaven.

1856. Harrison, George, Canada Works, Birkenhead.

1871. Harrison, Joseph Edward, Messrs. P. D. Bennett and Co.'s Works, Spon Lane Iron Foundry, Westbromwich.

1858. Harrison, Thomas Elliot, 1 Westminster Chambers, Victoria Street, Westminster, S.W.

1865. Harrison, William Arthur, Cambridge Street Works, Manchester.

1872. Hartnell, Wilson, Messrs. Tangye Brothers' Cornwall Works, Soho, Birmingham.

1871. Hartness, John, Lloyds' Inspector, Wear Chain and Anchor Testing Works, Sunderland.

1872. Hassall, Henry Thomas, Messrs. Hassall and Singleton, Phœnix Foundry, Freeman Street, Birmingham.

1858. Haswell, John A., North Eastern Railway, Locomotive Department, Gateshead.

1857. Haughton, S. Wilfred, Greenbank, Carlow, Ireland. (*Life Member.*)

1873. Hawkins, Charles W., Locomotive Superintendent, Great Indian Peninsula Railway, Byculla, Bombay.

1861. Hawkins, William Bailey, 2 Suffolk Lane, Cannon Street, London, E.C.

1870. Hawksley, Charles, 30 Great George Street, Westminster, S.W.

1856. Hawksley, Thomas, 30 Great George Street, Westminster, S.W.
1873. Hay, James A. C., Assistant to Superintendent of Machinery, War Department, Royal Arsenal, Woolwich, S.E.
1862. Haynes, Thomas John, Calpe Foundry, North Front, Gibraltar.
1869. Head, Jeremiah, Messrs. Fox Head and Co., Newport Rolling Mills, Middlesbrough.
1860. Head, John, Messrs. Ransomes Sims and Head, Orwell Works, Ipswich.
1853. Headly, James Ind, Eagle Foundry, Mill Road, Cambridge.
1873. Headly, Lawrance, Eagle Foundry, Mill Road, Cambridge.
1857. Healey, Edward Charles, 163 Strand, London, W.C.
1872. Heap, William, Bank Chambers, Cook Street, Liverpool.
1864. Heathfield, Richard, Lion Galvanising Works, Wiggin Street, Icknield Port Road, Birmingham.
1868. Heaton, John, Langley Mill Steel and Iron Works, near Nottingham.
1869. Henderson, David Marr, Engineer-in-Chief, Imperial Maritime Customs Service of China, Shanghai, China.
1865. Hetherington, John Muir, Vulcan Works, Pollard Street, Manchester.
1866. Hetherington, Thomas Ridley, Vulcan Works, Pollard Street, Manchester.
1864. Hetherington, William Isaac, 84 King William Street, London Bridge, London, E.C.
1865. Hewitt, Edward Edwards, High Court, High Street, Sheffield.
1872. Hewlett, Alfred, Wigan Coal and Iron Works, Kirkless Hall, Wigan.
1871. Hick, John, M.P., Hill Top, Sharples, near Bolton.
1866. Hickman, George Haden, Groveland Iron Works, Dudley Port, Tipton.
1864. Hide, Thomas C., Messrs. Hide and Thompson, 4 Cullum Street, Fenchurch Street, London, E.C.
1870. Higson, John, Mining Engineer, St. George's Chambers, Albert Square, Manchester.
1873. Hildebrandt, John Albert Reinhold, Bow Chambers, 55 Cross Street, Manchester.
1871. Hill, Alfred C., Royal Exchange, Middlesbrough; and Newcomen Street, Coatham, Redcar.
1867. Hill, Henry Walker, 51 Hampden Street, Nottingham.
1873. Hilton, Franklin, West Cumberland Iron and Steel Works, Workington.
1869. Hind, Henry, Central Works, Queen's Road, Nottingham.
1870. Hodges, Petronius, Yorkshire Steel and Iron Works, Penistone, near Sheffield.
1866. Hodgson, Charles, 21 Gresham Street, Old Jewry, London, E.C.
1858. Hodgson, Robert, North Eastern Railway, Newcastle-on-Tyne.
1852. Holcroft, James, Norton, near Stourbridge.
1866. Holcroft, Thomas, Bilston Foundry, Bilston.
1871. Holiday, Joseph, Union Foundry, Cutler Heights, near Bradford, Yorkshire.

1865. Holliday, John, Meyrick House, Hill Top, Westbromwich.
1863. Holt, Francis, Messrs. Hawthorn's Engine Works, Newcastle-on-Tyne.
1873. Holt, Henry Percy, Royal Insurance Buildings, Leeds.
1867. Holt, William Lyster, 7 Great Winchester Street Buildings, London, E.C.
1867. Homer, Charles James, Mining Engineer, Chatterley Ironstone Works, Tunstall, near Stoke-upon-Trent.
1848. Homersham, Samuel Collett, 19 Buckingham Street, Adelphi, London, W.C.
1860. Hopkins, James Innes, 3 Southwell Gardens, Gloucester Road, South Kensington, London, S.W.
1866. Hopkins, John Satchell, Tinplate Works, Granville Street, Birmingham.
1856. Hopkinson, John, Messrs. Wren and Hopkinson, London Road Iron Works, Manchester.
1867. Hopper, William, Machine Works, Moscow : (or care of Thomas Hopper, 5 South Frederick Street, Edinburgh.)
1873. Horsley, Charles, 22 Wharf Road, City Road, London, N.
1868. Horsley, Thomas, Kirkby Old Hall, Pinxton, Alfreton.
1858. Horsley, William, Jun., Whitehill Point Iron Works, Percy Main, near Newcastle-on-Tyne.
1868. Horton, Enoch, Alma Works, Darlaston, near Wednesbury.
1871. Horton, George, Messrs. Horton and Son, Steam Boiler Works, 63 Park Street, Southwark, London, S.E.
1867. Horton, Thomas Ellwood, Lilleshall Iron Works, Oakengates, near Wellington, Shropshire.
1873. Hoskin, Richard, Messrs. Alexander and Hoskin, Corinium Iron Works, Cirencester.
1873. Hosking, John, Gateshead Iron Works, Gateshead.
1866. Houghton, John Campbell Arthur, Messrs. Cochrane and Co.'s, Woodside Iron Works, near Dudley.
1864. Howard, Eliot, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.
1860. Howard, James, M.P., Messrs. J. and F. Howard, Britannia Iron Works, Bedford.
1867. Howard, Robert Luke, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.
1860. Howe, William, Clay Cross Coal and Iron Works, near Chesterfield.
1861. Howell, Joseph Bennett, Brook Steel Works, Brookhill, Sheffield.
1867. Hughes, George Douglas, Queen's Foundry, London Road, Nottingham.
1873. Hughes, Henry, Falcon Iron Works, Loughborough.
1871. Hughes, Joseph, 21 Worcester Street, Stourbridge.
1864. Hulse, William Wilson, Whalley Chambers, 88 King Street, Manchester.
1866. Humphrys, Robert Harry, Deptford Pier, London, S.E.

1870. Hunstone, William Henry, Springfield Iron Works, Salford, Manchester.
1859. Hunt, James P., Corngreaves Iron Works, near Birmingham.
1856. Hunt, Thomas, 143 Nottingham Street, Sheffield.
1872. Hunter, John Law, Borough Engineer, Wigan.
1864. Hutchinson, Edward, Messrs. Pease Hutchinson and Co., Skerne Iron Works, Darlington.
1865. Hyde, Lt.-Colonel Henry, R.E., Master of the Mint, Calcutta : (or care of Rev. H. M. C. Hyde, 184 The Grove, Camberwell, London, S.E.) (*Life Member.*)

1867. Inglis, William, Messrs. Hick Hargreaves and Co.'s, Soho Iron Works, Bolton.
1872. Inman, Charles Arthur, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead.
1866. Ireland, William, care of Jonathan Ireland, Edward Street, Broughton Lane, Manchester.

1872. Jack, Alexander, Messrs. James Jack, Rollo, and Co., Victoria Engine Works, Boundary Street West, Vauxhall Road, Liverpool.
1870. Jackson, John P., Mining Engineer, Clay Cross Coal and Iron Works, near Chesterfield.
1859. Jackson, Matthew Murray, Engineer-in-Chief, Imperial Danube Steam Navigation Works, Pesth, Austria.
1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester.
1860. Jackson, Samuel, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.
1873. Jackson, Samuel, Assistant Locomotive Superintendent, Great Indian Peninsula Railway, Bombay : (or care of W. Albert Jackson, 1 Mulberry Street, Sheffield.)
1872. Jackson, William Francis, Atlas Steel and Iron Works, Sheffield.
1873. Jacob, Edward Westley, Windsor Iron Works, Garston, near Liverpool.
1866. Jaeger, Herrmann Frederic, Messrs. Beyer Peacock and Co.'s Works, Gorton Foundry, Manchester.
1858. Jaffrey, George William, 40 St. Enoch Square, Glasgow ; and The Firs, Partick Hill, Glasgow.
1856. James, Jabez, 40 Prince's Street, Commercial Road, Lambeth, London, S.E.
1868. James, John, Sunny Bank, Pontypool.
1870. Jamieson, John Lennox Kincaid, Messrs. John Elder and Co., Engineers and Shipbuilders, 12 Centre Street, Glasgow ; and Govan.
1861. Jeffcock, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.
1863. Jeffreys, Edward A., Low Moor Iron Works, near Bradford, Yorkshire.

1861. Jessop, Thomas, Park and Brightside Steel Works, Sheffield.
1854. Jobson, John, Derwent Foundry, Derby.
1863. Johnson, Bryan, Messrs. Johnson and Ellington, Flookersbrook Foundry, Chester.
1861. Johnson, Samuel Waite, Locomotive Superintendent, Midland Railway, Derby.
1872. Joicey, Jacob Gowland, Messrs. J. and G. Joicey and Co., Forth Banks West Factory, Newcastle-on-Tyne.
1872. Jones, Charles, Messrs. John Jones and Sons, Marine Engine Works, William Street, Liverpool.
1871. Jones, Charles Henry, Assistant Locomotive Superintendent, Midland Railway, Derby.
1847. Jones, Edward, Wylde Green, Erdington, near Birmingham.
1873. Jones, Edward, National Arms and Ammunition Works, Belmont Row, Birmingham.
1873. Jones, Edward Trygarn, Consulting Engineer to the Commercial Steam Ship Co., 32 Great St. Helen's, London, E.C.
1857. Jones, Hodgson, 104 Maida Vale, London, W.
1869. Jones, John, Iron Trade Offices, Royal Exchange, Middlesbrough.
1872. Jones, William Richard Sumption, Executive Engineer, Workshops Division, Lower Ganges Canal, Nurora, viâ Aligurh, India.

1857. Kay, James Clarkson, Phœnix Foundry, Bury, Lancashire.
1869. Keen, Arthur, Patent Nut and Bolt Works, Smethwick, near Birmingham.
1869. Keep, Alfred, Metal Sheathing Works, 10 Coleshill Street, Birmingham.
1867. Kellett, John, 27 King Street, Wigan.
1873. Kelson, Frederick Colthurst, Superintending Engineer, City of Cork Steam Packet Co., Cork.
1857. Kendall, William, Locomotive Superintendent, Blyth and Tyne Railway, Percy Main, near Newcastle-on-Tyne.
1863. Kennan, James, Agricultural Implement Works, 19 Fishamble Street, Dublin.
1847. Kennedy, James, Cressington Park, Aigburth, Liverpool.
1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway, 45 Finsbury Circus, London, E.C.; and 29 Lupus Street, St. George's Square, London, S.W.
1868. Kennedy, Thomas Stuart, Wellington Foundry, Leeds.
1866. Kershaw, John, 9 Great Queen Street, Westminster, S.W.
1867. Kimball, Frederick James, 35 South Third Street, Philadelphia, Pennsylvania, United States.
1872. King, William, Engineer, Liverpool United Gas Works, Duke Street, Liverpool.

1870. Kinsey, Henry, St. Helen's Engineering Works, Swansea.
1872. Kirk, Alexander Carnegie, Messrs. John Elder and Co., Engineers and Shipbuilders, 12 Centre Street, Glasgow; and Govan, Glasgow.
1847. Kirtley, Matthew, Locomotive Superintendent, Midland Railway, Derby.
1864. Kirtley, William, Midland Railway, Locomotive Department, Derby.
1859. Kitson, Frederick William, Monkbridge Iron Works, Leeds.
1848. Kitson, James, Airedale Foundry, Leeds.
1859. Kitson, James, Jun., Monkbridge Iron Works, Leeds.
1868. Kitson, John Hawthorn, Airedale Foundry, Leeds.

1872. Laird, Henry Hyndman, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.
1872. Laird, William, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.
1873. Lamb, William James, Newtown and Meadows Collieries, near Wigan.
1866. Lambert, William Blake, 6 Vanbrugh Park, Blackheath, London, S.E.
1863. Lancaster, John, M.P., Bilton Grange, Rugby.
1870. Lancaster, Joshua, Mostyn Coal and Iron Works, near Holywell.
1867. Lawrence, Henry, The Grange Iron Works, Durham.
1870. Layborn, Daniel, Messrs. Gladstone and Wyllie's Cotton Rice and Oil Factories, Rangoon, Burmah, India: (or care of Daniel Layborn, Sen., Beverley.)
1856. Laybourne, Richard, Rhymney Iron Works, Tredegar.
1860. Lea, Henry, 35 Paradise Street, Birmingham.
1865. Ledger, Joseph, Iron Ore Office, Workington.
1862. Lee, J. C. Frank, 22 Great George Street, Westminster, S.W.
1871. Lee, William, Messrs. Lee Clerk and Robinson, Gospel Oak Iron Works, Tipton.
1863. Lees, Samuel, Jun., Park Bridge Iron Works, Ashton-under-Lyne.
1863. Leigh, Evan, Town Hall Buildings, Manchester.
1866. Leigh, Joseph D., Ellesmere Foundry, Patricroft, near Manchester.
1870. Leonard, Edward James, East India Chambers, 23 Leadenhall Street, London, E.C.
1858. Leslie, Andrew, Iron Shipbuilding Yard, Hebburn Quay, Gateshead.
1872. Leslie, Bradford, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1872. Lewis, Richard Amelius, Messrs. John Spencer and Sons' Tyne Iron Works, Blaydon-on-Tyne, County Durham.
1872. Lewis, Rowland Watkin, Britannia Boiler Tube Works, Wolverhampton.
1860. Lewis, Thomas William, Mardy, Aberdare.
1856. Linn, Alexander Grainger, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1872. Linsley, Samuel W., Engineer, Silksworth Colliery, near Sunderland.

1866. Little, George, Messrs. Platt Brothers and Co.'s, Hartford Iron Works, Oldham.

1867. Livesey, James, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1873. Llewellyn, William Hely, Court Colman, near Bridgend, Glamorganshire.

1867. Lloyd, Charles, care of Edward J. Lloyd, 6 Victoria Grove, Fulham Road, London, S.W.

1863. Lloyd, Edward R., Albion Tube Works, Nile Street, Birmingham.

1871. Lloyd, Francis Henry, Old Park Iron Works, Wednesbury.

1854. Lloyd, George Braithwaite, Messrs. Lloyds, High Street, Birmingham. (*Life Member.*)

1862. Lloyd, John, Lilleshall Iron Works, Oakengates, near Wellington, Shropshire.

1866. Lloyd, Joseph Foster, 1 Temple Row West, Birmingham.

1847. Lloyd, Sampson, Old Park Iron Works, Wednesbury; and Wassell Grove, near Stourbridge.

1864. Lloyd, Sampson Zachary, Old Park Iron Works, Wednesbury.

1852. Lloyd, Samuel, The Farm, Sparkbrook, Birmingham.

1862. Lloyd, Wilson, Darlaston Green Iron and Steel Works, near Wednesbury.

1863. Loam, Matthew Hill, Engineer of the Gas and Water Works, Nottingham.

1869. Lockhart, Humphrey Campbell, Messrs. Pilkington Brothers' Plate Glass Works, St. Helen's.

1856. Longridge, Robert Bewick, Chief Engineer, Steam Boiler Insurance Company, 67 King Street, Manchester.

1865. Longridge, William Smith, Alderwasley Iron Works, Ambergate, near Derby.

1866. Lord, Edward, Canal Street Works, Todmorden.

1861. Low, George, St. Peter's Iron Works, Ipswich.

1873. Lowe, John Edgar, Messrs. William Bird and Co.'s, 2 Laurence Pountney Hill, London, E.C.

1873. Lucas, Arthur, 18 Duke Street, Westminster, S.W.

1872. Lukin, Augustus Stephen, Borough Engineer, Carmarthen.

1854. Lynde, James Gascoigne, Town Hall, Manchester.

1868. Lyndon, George Frederick, Minerva Works, Fazeley Street, Birmingham.

1872. Lyster, George Fosbery, Engineer-in-Chief, Mersey Dock Estate, Liverpool.

1864. Macfarlane, Walter, Saracen Foundry, Washington Street, Glasgow.

1856. Mackay, John, Mount Hermon, Drogheda.

1864. Macnab, Archibald Francis, Japanese Government Service, Yokohama, Japan.

1865. MacNay, William, Shildon Engine Works, Darlington.

1865. Macnee, Daniel, Brinsworth Iron and Steel Works, Rotherham.

1873. Mair, John George, Messrs. Simpson and Co.'s Engine Works, Grosvenor Road, Pimlico, London, S.W.

1859. Manning, John, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds.

1862. Mansell, Richard Christopher, Carriage Superintendent, South Eastern Railway, Ashford.

1862. Mappin, Frederick Thorpe, Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.

1857. March, George, Union Foundry, Dewsbury Road, Leeds.

1856. Markham, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield.

1871. Marsh, Henry William, Winterbourne, near Bristol.

1865. Marshall, Francis Carr, Messrs. Hawthorn and Co., Newcastle-on-Tyne.

1862. Marshall, James, South Skelton Mines, Saltburn-by-the-Sea.

1871. Marshall, James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.

1859. Marshall, William Ebenezer, 1 Beech Grove Terrace, Leeds.

1847. Marshall, William Prime, 81 Newhall Street, Birmingham.

1859. Marten, Edward Bindon, Chief Engineer, Midland Steam Boiler Inspection and Assurance Company, 56 Hagley Street, Stourbridge.

1853. Marten, Henry John, Parkfield Iron Works, near Wolverhampton.

1867. Martin, William, 13 Avenue de la Reine Hortense, Paris.

1857. Martindale, Lt.-Colonel Ben Hay, C.B., R.E., General Manager, London and St. Katharine Docks, Dock House, 109 Leadenhall Street, London, E.C.

1854. Martineau, Francis Edgar, Globe Works, Cliveland Street, Birmingham.

1864. Martley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.W.

1857. Masselin, Armand, 372 Rue de Vaugirard, Paris.

1867. Mather, William, Messrs. Mather and Platt, Salford Iron Works, Manchester.

1853. Maudslay, Henry, care of John Maxwell, Rochford House, Beulah Hill, Upper Norwood, London, S.E. (*Life Member.*)

1869. Maughan, Thomas, Engineer, Cramlington Colliery, Cramlington, Northumberland.

1873. Maw, William Henry, 37 Bedford Street, Strand, London, W.C.

1869. May, George, Mining Engineer, Harton Collieries, Tyne Docks, South Shields.

1861. May, Robert Charles, 6 Great George Street, Westminster, S.W.

1857. May, Walter, Messrs. May and Mountain, Suffolk Works, Berkley Street, Birmingham.

1865. Maylor, John, Churton Lodge, Churton, near Chester.

1859. Maylor, William, Calicut, Madras.
1847. McClean, John Robinson, M.P., F.R.S., 23 Great George Street, Westminster, S.W.
1872. McConnochie, John, Engineer to the Bute Harbour Trust, New Works, Bute Docks, Cardiff.
1865. McDonnell, Alexander, Locomotive Superintendent, Great Southern and Western Railway, Dublin.
1867. McEwen, James, Messrs. Firmstone and McEwen, Lays Iron Foundry, near Stourbridge.
1864. McEwen, Lawrence Thompson, Lombard House, George Yard, Lombard Street, London, E.C.
1868. McKay, Benjamin, Manager, Small Arms Factory, Small Heath, near Birmingham.
1872. McNeile, Alexander, Messrs. McNeile Brothers, Wheel and Axle Works, 26 John Street, Pentonville Road, London, N.
1863. Meek, Sturges, Resident Engineer, Lancashire and Yorkshire Railway, Manchester.
1858. Meik, Thomas, Engineer to the River Wear Commissioners, 28 Fawcett Street, Sunderland.
1857. Menelaus, William, Dowlais Iron Works, Dowlais.
1866. Meredith, Alban, care of Messrs. Elkington and Co., Newhall Street, Birmingham.
1867. Merryweather, Richard M., Fire Engine Works, 63 Long Acre, London, W.C.
1862. Miers, Francis C., Stoneleigh Lodge, Grove Road, Clapham Park, London, S.W.
1864. Miers, John William, 74 Addison Road, Kensington, London, W.
1862. Millward, John, Curzon Chambers, 27 Paradise Street, Birmingham.
1856. Mitchell, Charles, Iron Shipbuilding Yard, Low Walker, Newcastle-on-Tyne.
1861. Mitchell, Joseph, Worsbrough Dale Colliery, near Barnsley; and Swaithe, near Barnsley.
1870. Moberley, Charles Henry, Messrs. Eastons and Anderson's, Erith Iron Works, Erith, London, S.E.
1873. Möller, Peter T., Mining Engineer, Admiralty, St. Petersburg.
1872. Moon, Richard, Jun., Mersey Steel and Iron Works, Caryl Street, Liverpool.
1859. Moor, William, Engineer, Hetton Colliery, Hetton, near Fence Houses.
1864. Moore, Sampson. North Foundry, Cotton Street, Clarence Dock, Liverpool.
1872. Moorsom, Warren Maude, London and North Western Railway, Locomotive Department, Crewe.
1864. Morgan, Joshua Llewelyn, Llanelly Iron and Tinplate Works, near Abergavenny.
1867. Morgans, Thomas, Newarne, Lydney.
1868. Morris, William, Waldridge Colliery, Chester-le-Street.
1865. Morton, Robert, Alliance Chambers, Borough, London, S.E.

1865. Mosse, James Robert, Public Works Office, Colombo, Ceylon.
1858. Mountain, Charles George, Messrs. May and Mountain, Suffolk Works, Berkley Street, Birmingham.
1873. Muir, Alfred, Messrs. William Muir and Co., Britannia Works, Sherborne Street, Strangeways, Manchester.
1873. Muir, Edwin, Engineer, Rochdale Canal Navigation, Rochdale.
1863. Muir, William, 59 Shardeloes Road, New Cross, London, S.E.
1872. Mulliner, Charles, Whalley Range, Manchester.
1865. Murdock, William Mallabey, Barrow Hæmatite Steel Works, Barrow-in-Furness.
1859. Murphy, James, Railway Works, Newport, Monmouthshire.
1858. Murray, Thomas H., Engine Works, Chester-le-Street.
1863. Musgrave, John, Jun., Globe Iron Works, Bolton.

1870. Napier, James Murdoch, Messrs. David Napier and Sons, Vine Street, York Road, Lambeth, London, S.E.
1848. Napier, John, Messrs. Robert Napier and Sons, Engineers and Shipbuilders, Lancefield House, Glasgow.
1856. Napier, Robert, West Shandon, Helensburgh. (*Life Member.*)
1861. Naylor, John William, Wellington Foundry, Leeds.
1858. Naylor, William, 57 Mildmay Park, Islington, London, N.
1863. Neilson, Walter Montgomerie, Hyde Park Locomotive Works, Glasgow.
1869. Nelson, James, King's House Engine Works and Foundry, Sunderland.
1860. Nettlefold, Joseph Henry, Screw Works, Broad Street, Birmingham.
1866. Newdigate, Albert Lewis, 10 Esplanade, Dover. (*Life Member.*)
1862. Newton, William Edward, 66 Chancery Lane, London, W.C.
1866. Norfolk, Richard, Beverley Iron and Wagon Works, Beverley.
1850. Norris, Richard Stuart, Wilton Cottage, Kenyon, near Manchester.
1868. Norris, William Gregory, Coalbrookdale Iron Works, near Wellington, Shropshire.
1869. North, Frederic William, Mining Engineer, Rowley Hall Colliery, Rowley Regis, near Dudley.
1870. Nye, Henry, Messrs. Varrall Elwell and Middleton's Works, 9 Avenue Trudaine, Paris.

1868. O'Connor, Charles, Messrs. John Elder and Co.'s, Fairfield Engine Works, Govan, Glasgow.
1866. Oliver, William, Victoria and Broad Oaks Foundries, Chesterfield.
1867. Olrick, Lewis, 27 Leadenhall Street, London, E.C.
1864. Ommanney, Frederick Francis, New Bridge Foundry, Adelphi Street, Salford, Manchester.
1870. Osborn, Samuel, Clyde Steel Works, Sheffield.

1870. Osman, Joseph, Bey, Chief Engineer and Superintendent of Factories to the Khedive of Egypt, Boulac, Cairo; and St. James' Hotel, 77 Piccadilly, London, W.

1867. Oughterson, George Blake, Messrs. Manlove Alliott and Co., 45 Rue d'Elbeuf, Rouen, France.

1847. Owen, William, Clifton House, Rotherham.

1868. Paget, Arthur, Machine Works, Loughborough.

1869. Palmer, Alfred Septimus, Mining Engineer, Quayside, Newcastle-on-Tyne.

1871. Parke, Frederick, Withnell Fire Clay Works and Cotton Mill, near Chorley.

1868. Parker, Henry, Locomotive Superintendent, Mexican Railway, Puebla, Mexico: (or care of Frederick Parker, 117 Unett Street, Birmingham.)

1869. Parker, Thomas, Mersey Wheel Works, Stourbridge.

1872. Parker, Thomas, Carriage Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.

1871. Parkes, Pershouse, Tipton Chain Works, Castle Street, Tipton.

1866. Parton, Thomas, Mining Engineer, Ash Cottage, Birmingham Road, Westbromwich.

1872. Paxman, James Noah, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester.

1869. Peacock, Ralph, Messrs. Beyer Peacock and Co.'s Works, Gorton Foundry, Manchester.

1869. Peacock, Ralph, Aire and Calder Foundry, Goole.

1847. Peacock, Richard, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1873. Pearce, Richard, Deputy Carriage Superintendent, East Indian Railway, Calcutta.

1867. Pearce, Robert Webb, Carriage Superintendent, East Indian Railway, Calcutta.

1848. Pearson, John, 7 Old Hall Street, Liverpool.

1869. Pearson, William Hall, 50 Ann Street, Birmingham.

1866. Peel, George, Jun., Soho Iron Works, Pollard Street, Manchester.

1866. Peele, Arthur John, Oakley House, Bellevue, Shrewsbury.

1848. Penn, John, F.R.S., The Cedars, Lee, London, S.E. (*Life Member.*)

1873. Penn, John, Jun., Messrs. John Penn and Sons, Marine Engineers, Greenwich, S.E.

1873. Penn, William, Messrs. John Penn and Sons, Marine Engineers, Greenwich, S.E.

1861. Perkins, Loftus, 6 Seaford Street, Regent Square, London, W.C.

1866. Perks, John Hartley, Shrubbery Iron Works, Wolverhampton; and Slade Hill, Wolverhampton.

1863. Perry, Thomas J., Highfields Engine Works, Bilston.
1865. Perry, William, Messrs. Samuel Perry and Sons, Wednesbury.
1869. Pickersgill, Thomas, Mining Engineer, Waterloo Main Colliery, Leeds.
1867. Pidgeon, Daniel, Messrs. Samuelson and Co., Britannia Iron Works, Banbury.
1871. Platt, James, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester.
1867. Platt, Samuel Radcliffe, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.
1870. Platt, William Wilkinson, Messrs. Mather and Platt, Salford Iron Works, Manchester; and Seymour Grove, Old Trafford, Manchester.
1869. Player, John, Clydach Foundry, near Swansea.
1866. Plum, Thomas Edward Day, Phœnix Wheel Tyre and Axle Works, Rotherham.
1861. Plum, Thomas William, Trimsaran Coal and Iron Works, near Ferryside, Carmarthenshire.
1872. Pole, William, F.R.S., 3 Storey's Gate, Westminster, S.W.
1860. Ponsonby, Edward Vincent, 1 Torquay Villa, Maindee, Newport, Monmouthshire.
1866. Porter, Charles Talbot, Allen Engine Works, Fourth Avenue, Harlem, New York.
1869. Potter, William Aubone, Mining Engineer, Cramlington House, Cramlington, Northumberland.
1864. Potts, Benjamin Langford Foster, 174 Camberwell Grove, London, S.E.
1851. Potts, John Thorpe, 5 Pemberton Square, Boston, Massachusetts, United States.
1870. Powell, Thomas, Messrs. Thomas and T. Powell, 23 Rue St. Julien, Rouen, France.
1867. Powell, William, Harbour Works, Douglas, Isle of Man.
1867. Pratchitt, John, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.
1865. Pratchitt, William, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.
1856. Preston, Francis, Turnbridge Forge, Huddersfield.
1866. Price, John, Chief Surveyor, Underwriters' Registry for Iron Vessels, 37 West Sunniside, Sunderland.
1866. Putnam, William, Darlington Forge, Darlington.

1873. Radcliffe, Arthur Henry Wright, 7 Union Street, Birmingham.
1870. Radcliffe, William, Messrs. Hampton Radcliffe and Co., Phœnix Bessemer Steel Works, The Ickles, near Sheffield.
1868. Rafarel, Frederic William, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.
1864. Ramage, Robert, 95 Miles Street, Liverpool.

1847. Ramsbottom, John, Harewood Lodge, Mottram, near Manchester.
1866. Ramsden, Sir James, Abbot's Wood, Barrow-in-Furness.
1860. Ransome, Allen, Jun., 304 King's Road, Chelsea, London, S.W.
1869. Ransome, Robert Charles, Messrs. Ransomes Sims and Head, Orwell Works, Ipswich.
1862. Ransome, Robert James, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich.
1873. Rapier, Richard Christopher, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich ; and 5 Westminster Chambers, Victoria Street, Westminster, S.W.
1867. Ratcliff, Daniel Rowlinson, Messrs. Thomas Milner and Son, Phœnix Safe Works, Smithdown Lane, Edge Hill, Liverpool.
1867. Ratliffe, George, Mersey Steel and Iron Co.'s Works, Caryl Street, Liverpool.
1862. Ravenhill, John R., Glass House Fields, Ratcliff, London, E.
1872. Rawlins, John, Manager, Metropolitan Carriage and Wagon Co., Saltley Works, Birmingham.
1870. Reed, Edward James, C.B., 8 Victoria Chambers, Victoria Street, Westminster, S. W.
1859. Rennie, George Banks, 20 Lowndes Street, Lowndes Square, London, S.W.
1862. Reynolds, Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.
1866. Richards, Edward Windsor, Ebbw Vale Iron Works, near Beaufort, Monmouthshire.
1856. Richards, Josiah, Pontypool Iron and Tinplate Works, Pontypool.
1863. Richardson, The Hon. Edward, Minister of Public Works, Christchurch, New Zealand.
1865. Richardson, John, Methley Park, near Leeds.
1873. Richardson, John, Messrs. Robey and Co.'s Engine Works, Lincoln.
1859. Richardson, William, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.
1873. Rickaby, Alfred Austin, Messrs. William Pile and Co.'s Engineering and Iron Ship Building Works, North Sands, Monkwearmouth, Sunderland.
1863. Rigby, Samuel, Messrs. Armitage and Rigbys, Cock Hedge Mill, Warrington.
1871. Rigg, John, Deputy Locomotive Superintendent, London and North Western Railway, Crewe.
1873. Robertson, George, Messrs. Vickarys and Robertson, West of England Engineering Works, Exeter.
1848. Robertson, Henry, Great Western Railway, Shrewsbury.
1865. Robey, Robert, Perseverance Iron Works, Lincoln.

1873. Robey, Robert, Jun., Messrs. Robey and Co.'s Engine Works, Lincoln.
1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester; and Westwood Hall, Leek, near Stoke-upon-Trent.
1865. Robinson, John, Messrs. Thomas Robinson and Son, Railway Works, Rochdale.
1866. Robson, Thomas, Mining Engineer, Lumley Colliery, Fence Houses.
1872. Rofe, Henry, Jun., Resident Engineer, Corporation Water Works, Rochdale.
1868. Rogers, William, Imperial Railway Department, Osaka, Japan.
1871. Rollo, David, Messrs. James Jack, Rollo, and Co., Victoria Engine Works, Boundary Street West, Vauxhall Road, Liverpool.
1853. Ronayne, Joseph P., Rinn Ronain, Queenstown, Ireland.
1867. Rose, Henry Fullwood, Albert Iron Works, Moxley, near Wednesbury.
1866. Rose, Thomas, Bradley Iron Works, near Bilston ; and Merridale Grove, Wolverhampton.
1867. Rose, Thomas, Machine Works, 37 Victoria Street, Manchester.
1869. Rose, William Napoleon, Albert Iron Works, Moxley, near Wednesbury.
1866. Rosthorn, Joseph De, Messrs. Rosthorn Brothers, Vienna.
1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Peterborough.
1857. Routledge, William, 4 Parsonage Buildings, Blackfriars, Manchester.
1860. Rumble, Thomas William, 15 George Street, Mansion House, London, E.C. (*Life Member.*)
1867. Ruston, Joseph, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln.
1866. Ryland, Frederick, Messrs. Kenrick's Works, Spon Lane, Westbromwich.

1866. Sacré, Alfred Louis, 1 Mornington Crescent, Regent's Park, London, N.W.
1859. Sacré, Charles, Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.
1868. Sacré, Edward Antoine, 26 Parliament Street, Westminster, S.W.
1864. Said, Colonel M., Pasha, Engineer, Turkish Service, Constantinople: (or care of J. C. Frank Lee, 22 Great George Street, Westminster, S.W.)
1872. Salmon, Frank Barton, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead.
1859. Salt, George, Saltaire, near Bradford, Yorkshire.
1864. Samuda, Joseph D'Aguilar, M.P., Iron Ship Building Yard, Isle of Dogs, Poplar, London, E.
1848. Samuel, James, 5 Westminster Chambers, Victoria Street, Westminster, S.W.
1857. Samuelson, Alexander, 27 Cornhill, London, E.C.
1865. Samuelson, Bernhard, M.P., Britannia Iron Works, Banbury.

1865. Sandberg, Christer Peter, Engineer, Swedish Government Railway Service; 19 Great George Street, Westminster, S.W.

1871. Sanders, Richard David, Assistant Locomotive Superintendent, Great Indian Peninsula Railway, Bombay: (or care of George Sanders, Bank of England, London, E.C.)

1861. Sanderson, George Grant, Redbourn Hill Iron and Coal Works, Frodingham, near Brigg.

1864. Sanderson, John, Weardale and Shildon District Water Works, Tunstall Reservoir, Wolsingham, near Darlington.

1869. Scarlett, James, 14 St. Ann's Square, Manchester.

1869. Schanschieff, Alexandre, Nevsky Prospeckt, No. 4, Log. 3, St. Petersburg.

1866. Scholtze, Aleksander, Messrs. Scholtze Brothers, Engineers and Boiler Makers, Warsaw, Poland.

1868. Scott, George Lamb, Crown Iron Works, Heywood Street, Clowes Street, West Gorton, Manchester.

1861. Scott, Walter Henry, Locomotive and Carriage Superintendent, Mauritius Railways, Port Louis, Mauritius: (or care of James H. Murray, 16 Brunswick Street, Barnsbury Road, London, N.)

1868. Scriven, Charles, Messrs. Scriven and Holdsworth, Leeds Old Foundry, Marsh Lane, Leeds.

1864. Seddon, John, 98 Wallgate, Wigan.

1873. Seddon, John Frederick, Mining Engineer, Great Harwood Collieries, near Accrington.

1857. Selby, George Thomas, Smethwick Tube Works, Birmingham.

1867. Selby, Millin, Teakova Cotton Mill, near Ivanova, Vladimir, Russia: (or care of Atherton T. Selby, Atherton Old Hall, Leigh, near Manchester.)

1865. Sellers, William, Pennsylvania Avenue, Philadelphia, Pennsylvania, United States.

1872. Shanks, Arthur, Messrs. A. Burn and Co., Engineers and Contractors, 7 Hastings Street, Calcutta.

1863. Sharp, Henry, Bolton Iron and Steel Works, Bolton.

1867. Sharpe, Charles James, 17B Great George Street, Westminster, S.W.

1862. Sharpe, William John, 1 Victoria Street, Westminster, S.W.

1869. Sharrock, Samuel, Windsor Iron Works, Garston, near Liverpool.

1864. Shaw, Duncan, Mining Engineer, Cordoba, Spain.

1856. Shelley, Charles Percy Bysshe, 113 Victoria Street, Westminster, S.W.

1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.

1872. Shirley, Henry Lionel, Engineer, Constantinovskoi Railway, South Russia; and 9 Queen's Gate Terrace, London, S.W.

1872. Shoolbred, James Nelson, 3 York Buildings, Dale Street, Liverpool.

1859. Shuttleworth, Joseph, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.

1851. Siemens, Charles William, D.C.L., F.R.S., 3 Great George Street, Westminster, S.W.; and 3 Palace Houses, Kensington Gardens, Bayswater Road, London, W.
1871. Simon, Henry, 7 St. Peter's Square, Manchester.
1847. Sinclair, Robert, 4 Westminster Chambers, Victoria Street, Westminster, S.W.
1857. Sinclair, Robert Cooper, Hartshill, near Atherstone.
1859. Slater, Isaac, Gloucester Wagon Works, Gloucester.
1853. Slaughter, Edward, Avonside Engine Works, St. Philip's, Bristol.
1866. Smethurst, Joseph, Guide Bridge Iron Works, Audenshaw, near Manchester.
1873. Smith, Charles, Manager, Messrs. Thomas Richardson and Sons, Hartlepool Iron Works, Hartlepool.
1866. Smith, Edward Fisher, The Priory Offices, Dudley.
1866. Smith, George Fereday, Grovehurst, Tunbridge Wells.
1860. Smith, Henry, Brierley Hill Iron Works, Brierley Hill.
1860. Smith, John, Brass Foundry, Traffic Street, Derby.
1857. Smith, Josiah Timmis, Ulverstone Hæmatite Iron Works, Barrow-in-Furness.
1859. Smith, Matthew, Caledonia Wire Mills, Halifax.
1857. Smith, William, 19 Salisbury Street, Strand, London, W.C.
1866. Smith, William, Eglinton Engine Works, Glasgow.
1863. Smith, William Ford, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester.
1871. Soames, Peter, 10 Southampton Street, Strand, London, W.C.
1859. Sokoloff, Colonel Alexander, Engineer, Russian Imperial Service, Steam Marine Department, Cronstadt, Russia: (or care of Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.)
1858. Sörensen, Bergerius, Engineer-in-Chief, Royal Norwegian Navy Department, Horten Dockyard, Norway: (or care of Henry Tottie, 5 Great Winchester Street Buildings, London, E.C.)
1865. Sparrow, Arthur, Lane End Iron Works, Longton, near Stoke-upon-Trent.
1865. Sparrow, William Mander, Osier Bed Iron Works, Wolverhampton.
1866. Spencer, Eli, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.
1867. Spencer, John W., Newburn Steel Works, Newcastle-on-Tyne.
1853. Spencer, Thomas, Black Ladies, Penkridge, near Stafford.
1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne.
1864. Spittle, Thomas, Cambrian Iron Foundry, Newport, Monmouthshire.
1862. Stableford, William, Oldbury Carriage Works, near Birmingham.
1869. Stabler, James, Messrs. Shand Mason and Co., Fire Engine Works, 75 Upper Ground Street, Blackfriars Road, London, S.E.

1869. Stenson, Foster, Coalville, near Leicester.

1868. Stenson, William Towndrow, Whitwick Colliery, Coalville, near Leicester.

1866. Stephens, John Classon, Messrs. Ross Stephens and Walpole, North Wall Iron Works, Dublin.

1868. Stephenson, George Robert, 24 Great George Street, Westminster, S.W.

1866. Stevenson, John, Acklam Iron Works, Middlesbrough.

1859. Stewart, Charles P., Messrs. Sharp Stewart and Co., Atlas Works, Manchester; and 92 Lancaster Gate, Hyde Park Gardens, London, W.

1851. Stewart, John, Blackwall Iron Works, Russell Street, Blackwall, London, E.

1867. Stirling, Patrick, Locomotive Superintendent, Great Northern Railway, Doncaster.

1864. Stokes, James Folliott, Rothney Cottage, Simla, India.

1873. Stonehouse, Marshall, Engineer to the Yniscedwyn Iron Steel and Coal Co., near Swansea.

1863. Storey, John Henry, Knott Mill Brass and Copper Works, Little Peter Street, Manchester.

1862. Strong, Joseph F., 3 Devonia Terrace, Newton Abbot.

1865. Stroudley, William, Locomotive Superintendent, London Brighton and South Coast Railway, Brighton.

1873. Strype, William George, Engineer to Messrs. A. Guinness Son and Co., James' Gate Brewery, Dublin.

1861. Sumner, William, 2 Brazenose Street, Manchester.

1870. Swann, James Vincent Russell, care of Messrs. A. and J. Swann, Engineers and Architects, Moscow, Russia.

1860. Swindell, James Evers, Parkhead Iron Works, Dudley; and Oldswinford, near Stourbridge.

1864. Swindell, James Swindell Evers, Cradley Iron Works, near Brierley Hill.

1859. Swingler, Thomas, Messrs. Eastwood Swingler and Co., Victoria Foundry, Litchurch, near Derby.

1872. Symington, William Weldon, Bowden Steam Mills, Market Harborough.

1861. Tangye, James, Messrs. Tangye Brothers, Cornwall Works, Soho, Birmingham; and Clement Street, Birmingham.

1859. Tannett, Thomas, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.

1873. Taylor, Charles Dyke, Mining Engineer, Devoran, Cornwall.

1861. Taylor, George, Messrs. Taylor Brothers and Co., Clarence Iron Works, Leeds.

1858. Taylor, James, Britannia Engine Works, Cleveland Street, Birkenhead.

1862. Taylor, John, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.

1873. Taylor, John, Midland Foundry, Queen's Road, Nottingham.

1867. Taylor, Joseph, Derwent Foundry, 99 Constitution Hill, Birmingham.

1862. Taylor, Richard, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.

1872. Teague, William, Mining Engineer, Tincroft Mines, Redruth.

1864. Tennant, Charles, The Glen, Innerleithen, near Edinburgh. (*Life Member.*)

1867. Thomas, Joseph Lee, 16 Holland Road, Kensington, London, W.

1864. Thomas, Thomas, Bronygarn Villa, Roath, Cardiff.

1857. Thompson, Robert, Haigh Foundry, near Wigan.

1862. Thompson, William, Messrs. Thompson and Boyd, Spring Gardens Engine Works, Newcastle-on-Tyne.

1868. Thomson, John, Engine Works, 36 Finnieston Street, Glasgow.

1870. Thomson, William Sparks, 6A Victoria Street, Westminster, S.W.

1868. Thornewill, Robert, Burton Iron Works, Burton-on-Trent.

1861. Thwaites, Robinson, Messrs. Thwaites and Carbutt, Vulcan Iron Works, Thornton Road, Bradford, Yorkshire.

1862. Tolmé, Julian Horn, 1 Victoria Street, Westminster, S.W.

1873. Tomkins, Edward, Magdala Villas, Liverpool Road South, Birkdale, Southport.

1857. Tomlinson, Joseph, Jun., Resident Engineer and Locomotive Superintendent, Metropolitan Railway, Chapel Street Works, Edgware Road, London, N.W.

1867. Tonks, Edmund, Brass Works, Moseley Street, Birmingham

1856. Tosh, George, North Lincolnshire Iron Works, Frodingham, near Brigg.

1860. Townsend, Thomas C., 16 Talbot Chambers, Shrewsbury.

1865. Trow, John James, Messrs. William Trow and Sons, Union Foundry, Wednesbury.

1873. Trow, Joseph, Messrs. William Trow and Sons, Union Foundry, Wednesbury; and Holyhead Road, Wednesbury.

1862. Troward, Charles, 8 Sussex Terrace, Camden Town, London, N.W.

1866. Turner, Frederick, Messrs. E. R. and F. Turner, St. Peter's Iron Works, Ipswich.

1872. Turton, Thomas, Liverpool Forge Company, Brunswick Dock, Liverpool.

1867. Tweddell, Ralph Hart, 31 Duke Street, Westminster, S.W.

1856. Tyler, Captain Henry Wheetley, R.E., Railway Department, Board of Trade, Whitehall, London, S.W.

1862. Upward, Alfred, 11 Great Queen Street, Westminster, S.W.

1872. Usher, Thomas, Messrs. Reay and Usher, South Hylton Iron Works, Sunderland.

1868. Vallance, Frederick Bevoley, 101 Cannon Street, London, E.C.
1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.
1865. Vickers, Albert, Messrs. Vickers Sons and Co., River Don Works, Sheffield.
1861. Vickers, Thomas Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1856. Waddington, John, 35 King William Street, London Bridge, London, E.C.
1865. Wainwright, William, West Central Wagon Works, Worcester.
1863. Wakefield, John, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Dublin.
1873. Waldenström, Eric Hugo, Manager, Broughton Copper Co.'s Works, Broughton Road, Manchester.
1872. Walker, Alexander, Locomotive Superintendent, Cambrian Railways, Oswestry.
1870. Walker, Alfred, Albion Iron Works, Aldwark, York.
1867. Walker, Benjamin, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds.
1864. Walker, Bernard Peard, Eagle Foundry, Broad Street, Birmingham.
1867. Walker, Charles Clement, Midland Iron Works, Donnington, near Newport, Shropshire; and Lilleshall Old Hall, near Newport, Shropshire.
1863. Walker, William Hugill, Messrs. Walker Eaton and Co., Wicker Iron Works, Sheffield.
1863. Wallace, William, Superintending Engineer, Montreal Ocean Steam Ship Works, Boundary Street North, Liverpool.
1865. Waller, George Arthur, Messrs. A. Guinness Son and Co., James' Gate Brewery, Dublin.
1868. Wallis, Herbert, Mechanical Superintendent, Grand Trunk Railway, Montreal, Canada.
1865. Walpole, Thomas, Messrs. Ross Stephens and Walpole, North Wall Iron Works, Dublin.
1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Handsworth, near Birmingham.
1856. Wardle, Charles Wetherell, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds.
1852. Warham, John R., Burton Iron Works, Burton-on-Trent.
1867. Watkin, William John Laverick, Mining Engineer, Pemberton Colliery, near Wigan.
1862. Watkins, Richard, Messrs. Jackson and Watkins, Canal Iron Works, Poplar, London, E.
1866. Watson, Robert, Engineer, Black Boy Collieries, Bishop Auckland.

1862. Webb, Francis William, Locomotive Superintendent, London and North Western Railway, Crewe.

1872. Welch, Edward John Cowling, Messrs. Francis Morton and Co., Naylor Street Iron Works, Liverpool.

1862. Wells, Charles, Moxley Iron and Steel Works, near Bilston.

1871. West, Henry Joseph, Messrs. Siebe and West, Mason Street, Lambeth, London, S.E.

1862. Westmacott, Percy Graham Buchanan, Sir William G. Armstrong and Co., Elswick Engine Works, Newcastle-on-Tyne.

1867. Weston, Thomas Aldridge, care of William T. Watts, 81 Parade, Birmingham.

1867. Wheatley, Thomas, Locomotive Superintendent, North British Railway, Glasgow.

1856. Wheeldon, Frederick R., Highfields Engine Works, Bilston; and 16 Waterloo Road, Wolverhampton.

1872. Whieldon, William, Messrs. Whieldon and Cooke, Collinge Engineering Works, 190 Westminster Bridge Road, Lambeth, London, S.E.

1864. White, Isaias, Messrs. Portilla and White, Engineers and Iron Ship Builders, Seville, Spain: (or care of Isaac White, Pontardulais, Llanelly.)

1868. Whitehead, Peter Ormerod, Ilex Cotton Mill, Rawtenstall, near Manchester.

1859. Whitham, James, Perseverance Iron Works, Kirkstall Road, Leeds.

1873. Whitley, John Robinson, Railway Works, Hunslet Road, Leeds.

1863. Whitley, Joseph, New British Iron Works, Corngreaves, near Birmingham.

1865. Whitley, Joseph, Railway Works, Hunslet Road, Leeds.

1869. Whittem, Thomas Sibley, Wyken Colliery, Coventry.

1866. Whitwell, Thomas, Thornaby Iron Works, Stockton-on-Tees.

1847. Whitworth, Sir Joseph, Bart., D.C.L., LL.D., F.R.S., 44 Chorlton Street, Portland Street, Manchester; and The Firs, Fallowfield, Manchester.

1859. Wickham, Lamplugh Wickham, Low Moor Iron Works, near Bradford, Yorkshire.

1868. Wigram, Reginald, Messrs. John Fowler and Co.'s Steam Plough and Locomotive Works, Leeds.

1867. Wilkes, Gilbert, Bordesley Tube Mills, Liverpool Street, Birmingham.

1867. Wilkes, John, Bordesley Tube Mills, Liverpool Street, Birmingham.

1868. Wilkieson, Colonel Charles Vaughan, R.E., care of Messrs. Richardson and Co., 23 Cornhill, London, E.C.

1865. Williams, Edward, Messrs. Bolckow Vaughan and Co.'s Iron Works, Middlesbrough.

1872. Williams, Sir Frederick Martin, Bart., M.P., Perran Foundry, Goonvrea, Perranarworthal, Cornwall.

1847. Williams, Richard, Patent Shaft Works, Wednesbury.

1859. Williams, Richard Price, 9 Great George Street, Westminster, S.W.
1869. Williams, Walter, Wednesbury Oak Iron Works, Tipton.
1873. Williams, William Lawrence, Manager, Messrs. Brown Brothers and Co., Rosebank Iron Works, Edinburgh.
1870. Willman, Charles, 1 Cleveland Terrace, Middlesbrough.
1856. Wilson, Edward, 9 Dean's Yard, Westminster, S.W.
1859. Wilson, George, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.
1867. Wilson, Henry, Phœnix Brass Works, Stockton-on-Tees.
1865. Wilson, James Edwards, Brunswick House, Bromley, Kent.
1863. Wilson, John Charles, 17 Gracechurch Street, London, E.C.
1857. Wilson, Robert, Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester.
1872. Wilson, Stephen, Engineer, Wearmouth Colliery, Sunderland.
1873. Wilson, Thomas Sipling, Engineer to the Native Guano Co., 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1865. Winby, Clifford Etches, Messrs. Winby Brothers, Atlas Iron Works, Cardiff.
1867. Winby, Frederick Charles, Messrs. Winby Brothers, Atlas Iron Works, Cardiff.
1862. Winby, William Edward, Rabone Bridge Iron Works, Smethwick, near Birmingham; and 77 Wellington Road, Edgbaston, Birmingham.
1872. Winn, Charles William, 30 Easy Row, Birmingham.
1872. Winstanley, Robert, Jun., Mining Engineer, Lancaster Avenue, Fennel Street, Manchester.
1859. Winter, Thomas Bradbury, 28 Moorgate Street, London, E.C.
1872. Wise, William Lloyd, Chandos Chambers, Buckingham Street, Aldephi, London, W.C.
1872. Withinshaw, John, Birmingham Engine Works, Wiggin Street, Icknield Port Road, Birmingham.
1871. Withy, Edward, Messrs. Withy and Alexander, Middleton Iron Shipbuilding Yard, Hartlepool.
1868. Wood, Lindsay, Mining Engineer, Southhill, near Chester-le-Street.
1869. Wood, Thomas James Vickers, Springfield Mill, Cleckheaton, near Normanton.
1873. Woodhead, John Proctor, 88 King Street, Manchester.
1851. Woodhouse, John Thomas, Mining Engineer, Midland Road, Derby.
1858. Woods, Hamilton, Liver Foundry, Ordsal Lane, Salford, Manchester.
1860. Worthington, Samuel Barton, Resident Engineer, London and North Western Railway, Manchester.
1866. Wren, Henry, Messrs. Wren and Hopkinson, London Road Iron Works, Manchester.

1870. Wright, George Benjamin, Goscote Iron Works, near Walsall.
1867. Wright, John Roper, Hallside Steel Works, Newton, near Glasgow.
1867. Wright, John Turner, Universe Rope Works, Garrison Street, Birmingham.
1859. Wright, Joseph, Metropolitan Carriage and Wagon Company, Saltley Works, Birmingham.
1860. Wright, Joseph, Neptune Forge, Tipton Green, Dudley.
1863. Wright, Owen, Broadwell Forge, Oldbury, near Birmingham.
1863. Wright, Peter, Railway Wheel Vice and Anchor Works, Dudley.
1871. Wright, William, District Engineer, Cornwall Railway, Lostwithiel.
1871. Wrightson, Thomas, Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.
1865. Wyllie, Andrew, Messrs. Forrester and Co., Vauxhall Foundry, Vauxhall Road, Liverpool.

1873. Young, Charles Frederic Trelawny, 112 St. Donatt's Road, New Cross, London, S.E.
1861. Yule, William, 102 New Canal, St. Petersburg.

HONORARY LIFE MEMBERS.

1865. Downing, Samuel, LL.D., Trinity College, Dublin.
1847. Fairbairn, Sir William, Bart., LL.D., F.R.S., The Polygon, Ardwick, Manchester.
1867. Morin, General Arthur, Director, Conservatoire National des Arts et Métiers, Paris.
1867. Tresca, Henri, Engineer Sub-Director, Conservatoire National des Arts et Métiers, Paris.

ASSOCIATES.

1865. Barker, Frederick, Leeds Iron Works, Leeds.
1873. Barry, William Henry, 7 Birchin Lane, London, E.C.
1868. Beale, Montague, 1 Great Winchester Street Buildings, London, E.C.
1867. Blinkhorn, William, London and Manchester Plate Glass Works, Sutton, St. Helen's.
1866. Crossley, John, British Plate Glass Works, Ravenhead, near St. Helen's.
1867. Dewhurst, John Bonny, Bellevue Cotton Mills, Skipton.
1863. Fisher, John, 32 Priory Street, Dudley.
1863. Forster, George Emmerson, Contractor's Office, Washington, County Durham.
1873. Freeman, William George, Messrs. John Freeman and Sons, Granite Works, Penryn, Cornwall.

1865. Gössell, Otto, 22 Moorgate Street, London, E.C.

1873. Griffiths, John Alfred, Toowoomba Foundry, Ruthven Street, Toowoomba, Queensland.

1865. Hall. John, 56 King Street, Manchester.

1872. Hewlett, William Henry, Wigan Coal and Iron Works, Kirkless Hall, Wigan.

1858. Lawton, Benjamin C., Corbridge, Northumberland.

1859. Leather, John Towlerton, Leventhorpe Hall, near Leeds. (*Life Associate.*)

1865. Longsdon, Alfred, Crown Buildings, Queen Victoria Street, London, E.C.

1860. Manby, Cordy, Castle Street, Dudley.

1868. Matthews, Thomas Bright, Phœnix Steel Works, Sheffield.

1865. Parry, David, Leeds Iron Works, Leeds.

1864. Parsons, Charles T., Ann Street, Birmingham.

1871. Patterson, John, Liverpool and Manchester District Bank, Spring Gardens, Manchester; and Craigdarragh, Belfast.

1856. Pettifor, Joseph, Midland Railway, Derby.

1859. Sherriff, Alexander Clunes, M.P., Great Western Railway, Worcester; and 10 Dean's Yard, Westminster, S.W.

1863. Storey, Thomas R., Bond Court House, Walbrook, London, E.C.

1864. Tennant, John, St. Rollox Chemical Works, Glasgow. (*Life Associate.*)

1864. Thornton, Falkland Samuel, Bradford Street, Birmingham.

1869. Varley. John, Farnley Iron Works, Leeds.

1865. Warden, Thomas, Lionel Street, Birmingham.

1858. Waterhouse, Thomas, Claremont Place, Sheffield. (*Life Associate.*)

GRADUATES.

1872. Armstrong, Thomas, Phœnix Steel Works, Sheffield.

1872. Bagshawe, Walter, Airedale Foundry, Leeds.

1869. Bainbridge, Emerson, Nunnery Colliery Offices, Sheffield.

1869. Blake, Frederick William, Birmingham Heath Boiler Works, Spring Hill, Birmingham.

1866. Butler, Thomas Snowden, Kirkstall Forge, near Leeds.

1873. Collingham, Robert Moss, Messrs. Robey and Co.'s Engine Works, Lincoln.

1873. Dobson, Richard Joseph Caistor, Messrs. Manlove Alliott and Co.'s Works, 45 Rue d'Elbeuf, Rouen, France.

1868. Dugard, William Henry, 77 Lower Loveday Street, Birmingham.

1873. Edmunds, John Sharp Wilbraham, Stephenson Metal Tube Works, Liverpool Street, Birmingham.

1869. Fenwick, Clennell, Victoria Docks Engine Works, Victoria Docks, London, E.

1867. Flavel, Sidney, Jun., Eagle Foundry, Leamington.
1850. Glydon, George, Spring Hill Tube and Metal Works, Eyre Street, Birmingham.
1867. Holland, George, care of John Holland, Navigation Old Yard, Castle, Northwich.
1867. Jones, George Edward, Horseley Iron Works, Tipton.
1868. Mappin, Frank, Messrs. Thomas Turton and Sons' Sheaf Works, Sheffield.
1867. Mayhew, Horace, Mining Engineer, Westhoughton, near Bolton.
1867. Mitchell, John, Swaithe Colliery, Barnsley.
1868. Moor, William, Jun., Lanelay Colliery, Llantrissant, Glamorganshire.
1872. Napier, Robert Twentyman, Messrs. Denny and Co.'s Engine Works, Dumbarton.
1867. Pearson, John Edward, Spring Colliery, Ince Hall, near Wigan.
1870. Pearson, Thomas Henry, Moss Side Iron Works, Ince, near Wigan.
1873. Ratcliff, John Francis, Phœnix Safe Works, Smithdown Lane, Edge Hill, Liverpool.
1873. Simpson, Alfred, Messrs. Fowler and McCollin's, Vulcan Iron Works, Scott Street, Hull.
1872. Slater, Alfred, Gloucester Wagon Works, Gloucester.
1870. Smith, Michael Holroyd, Caledonia Wire Mills, Halifax.
1871. Thurgood, Ernest Charles, Saffron Walden.
1868. Wicksteed, Joseph Hartley, Well House Foundry, Meadow Road, Leeds.
1872. Wilson, Alfred, 9 St. John's Terrace, Middlesbrough.

LOCKING RAILWAY SIGNALS.

Plate I.

Fig. 1. *Plan of Ordinary Junction.*

Scale 1/300th

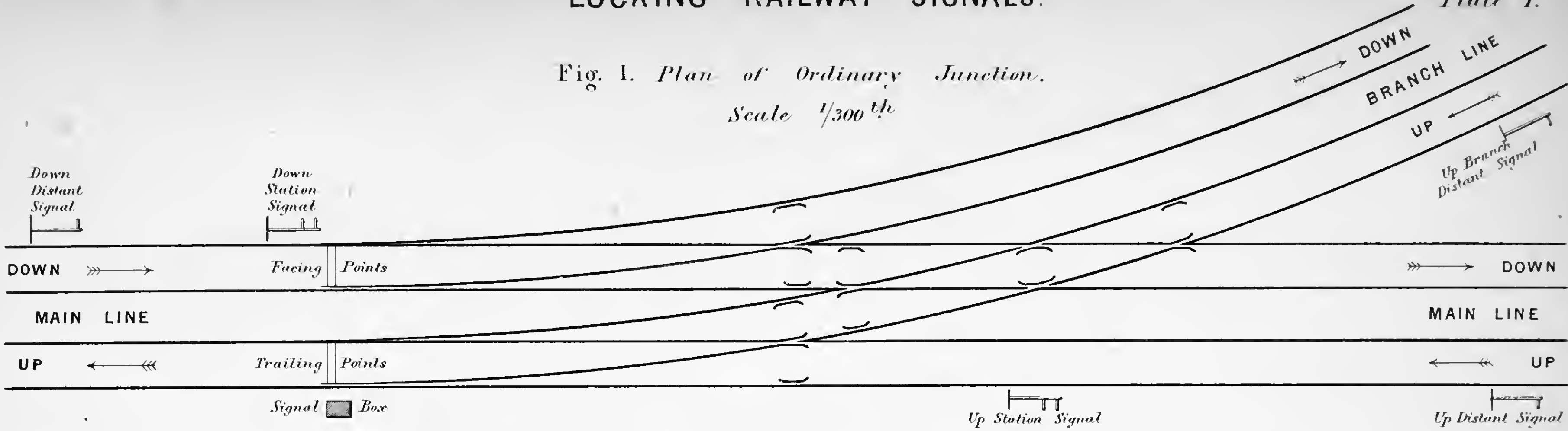
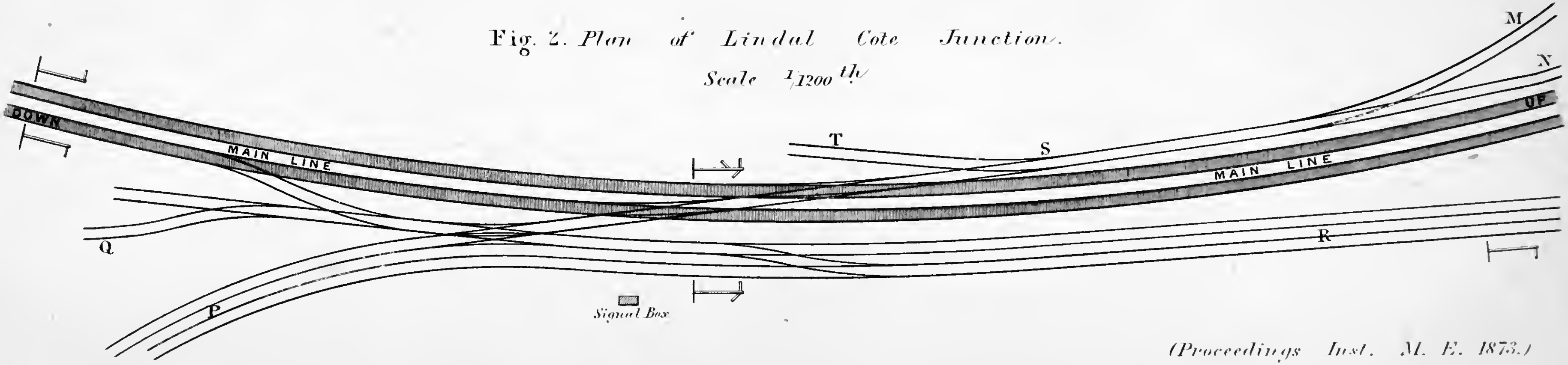


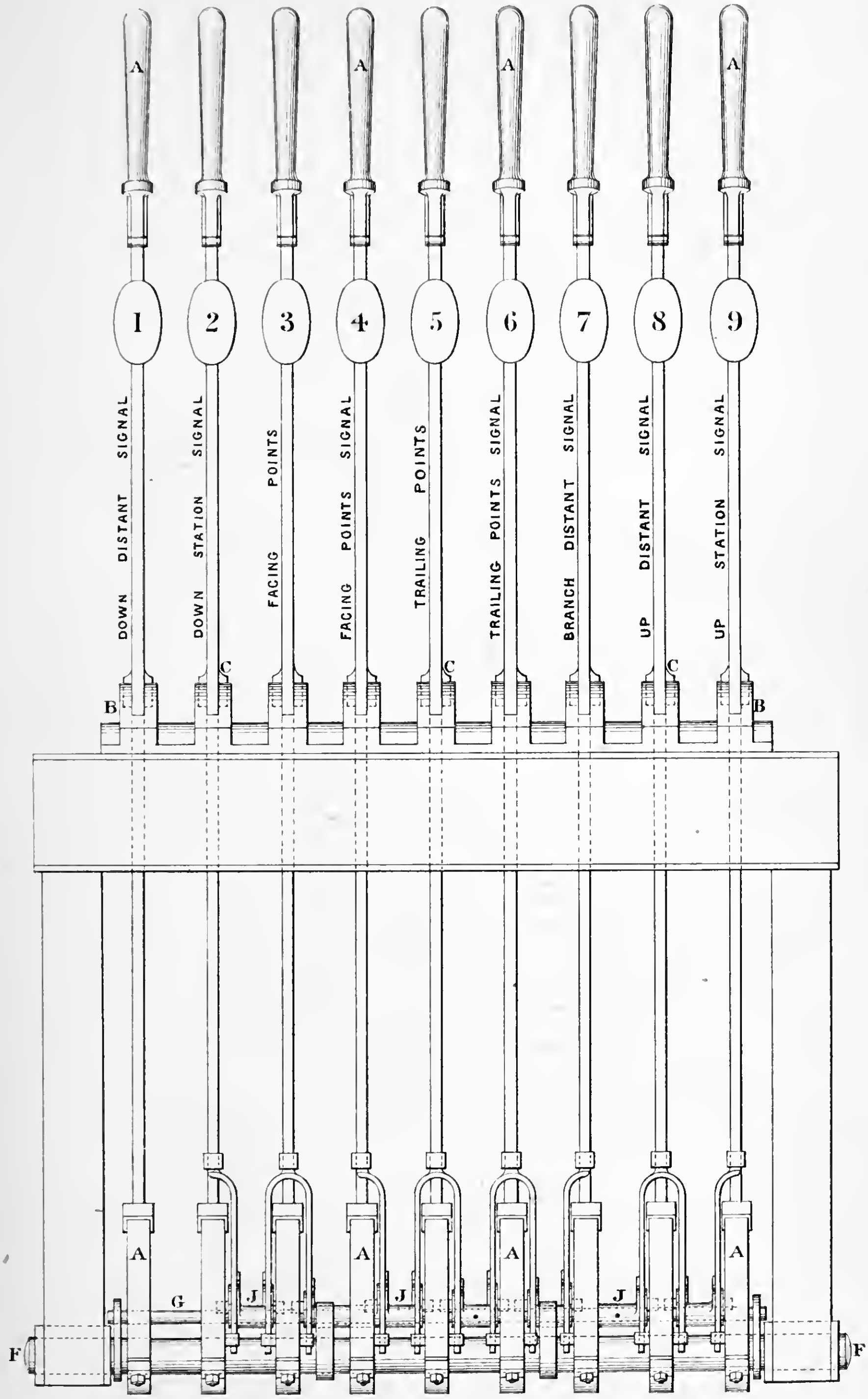
Fig. 2. *Plan of Lindal Cote Junction.*

Scale 1/1200th



(Proceedings Inst. M. E. 1873.)

Fig. 3. Elevation of Nine-Lever Locking Machine.



(Proceedings Inst. M. E. 1873.) *Scale 1/16th*

Inches 12 6 0 1 2 3 Feet.

Details of Locking Gear.

Scale 1/8th

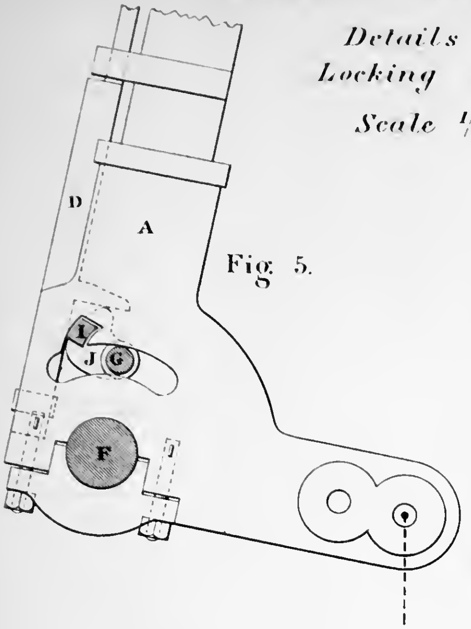


Fig. 5.

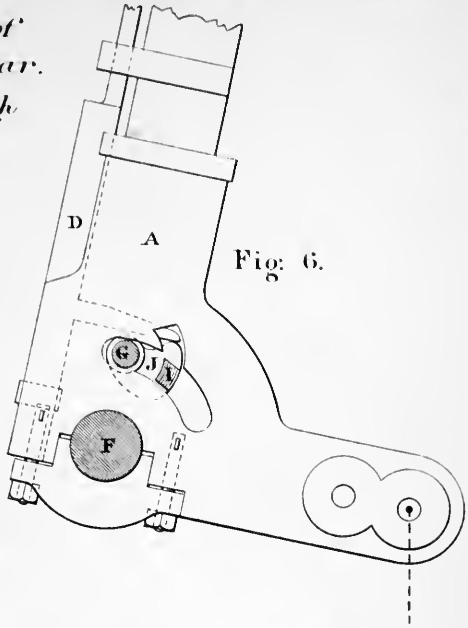
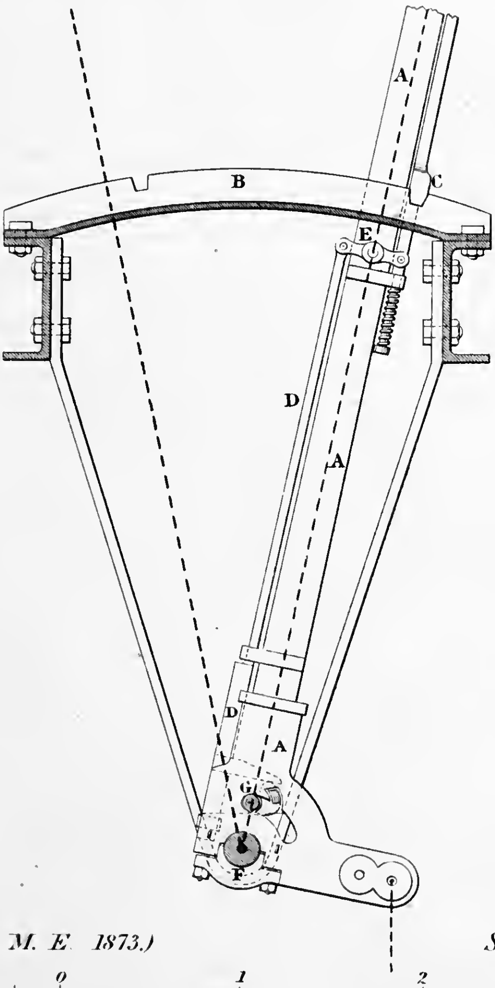


Fig. 6.

Fig. 4. *Transverse Section of Nine-Lever Locking Machine.*



(Proceedings Inst. M. E. 1873.)

Scale 1/16th

Inches 12 6 0 1 2 3 *Feet.*

LOCKING RAILWAY SIGNALS.

Plate 4.

Details of Locking Gear.

Nine-Lever Machine.

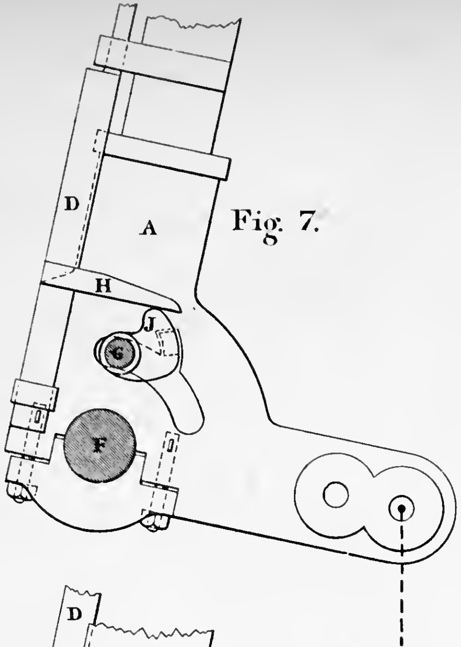


Fig. 7.

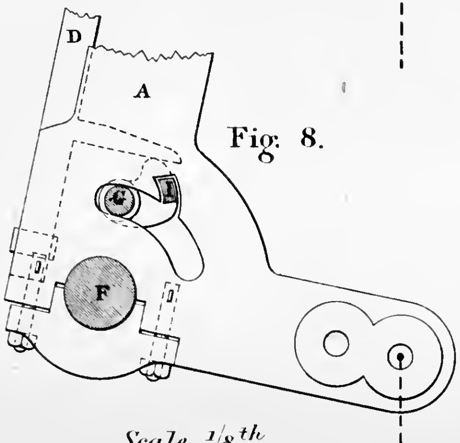


Fig. 8.

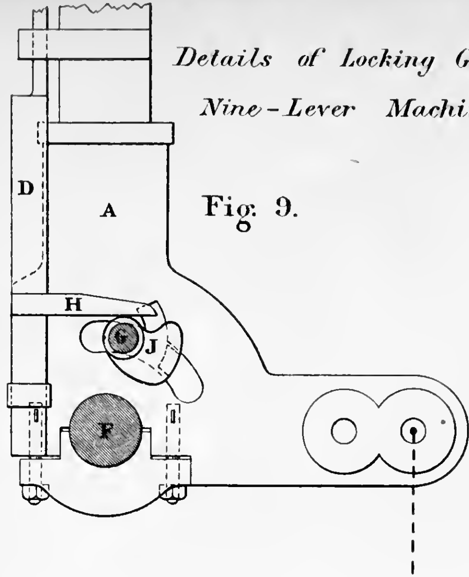


Fig. 9.

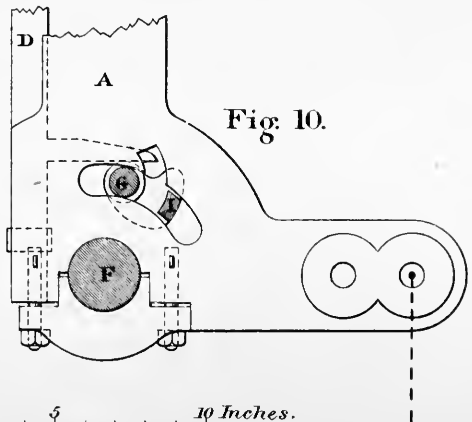


Fig. 10.

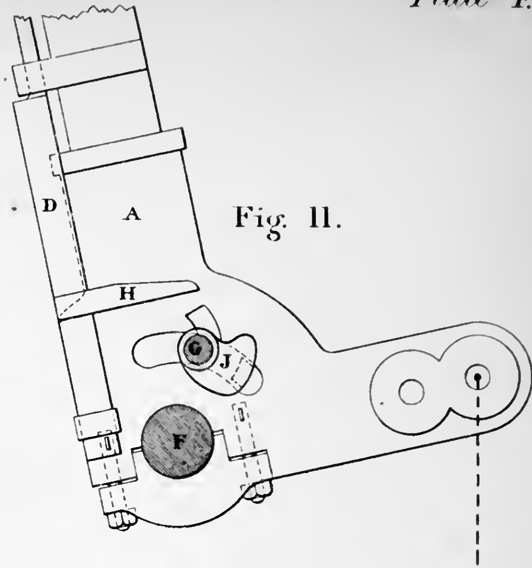


Fig. 11.

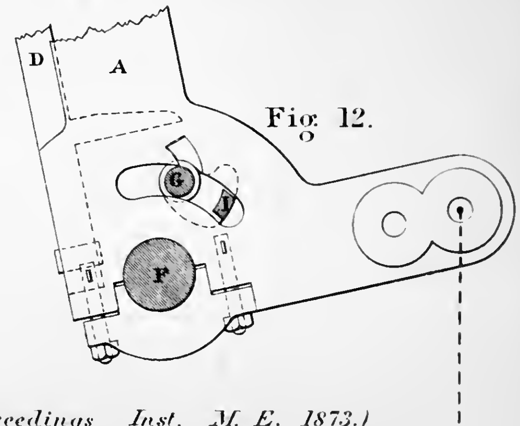
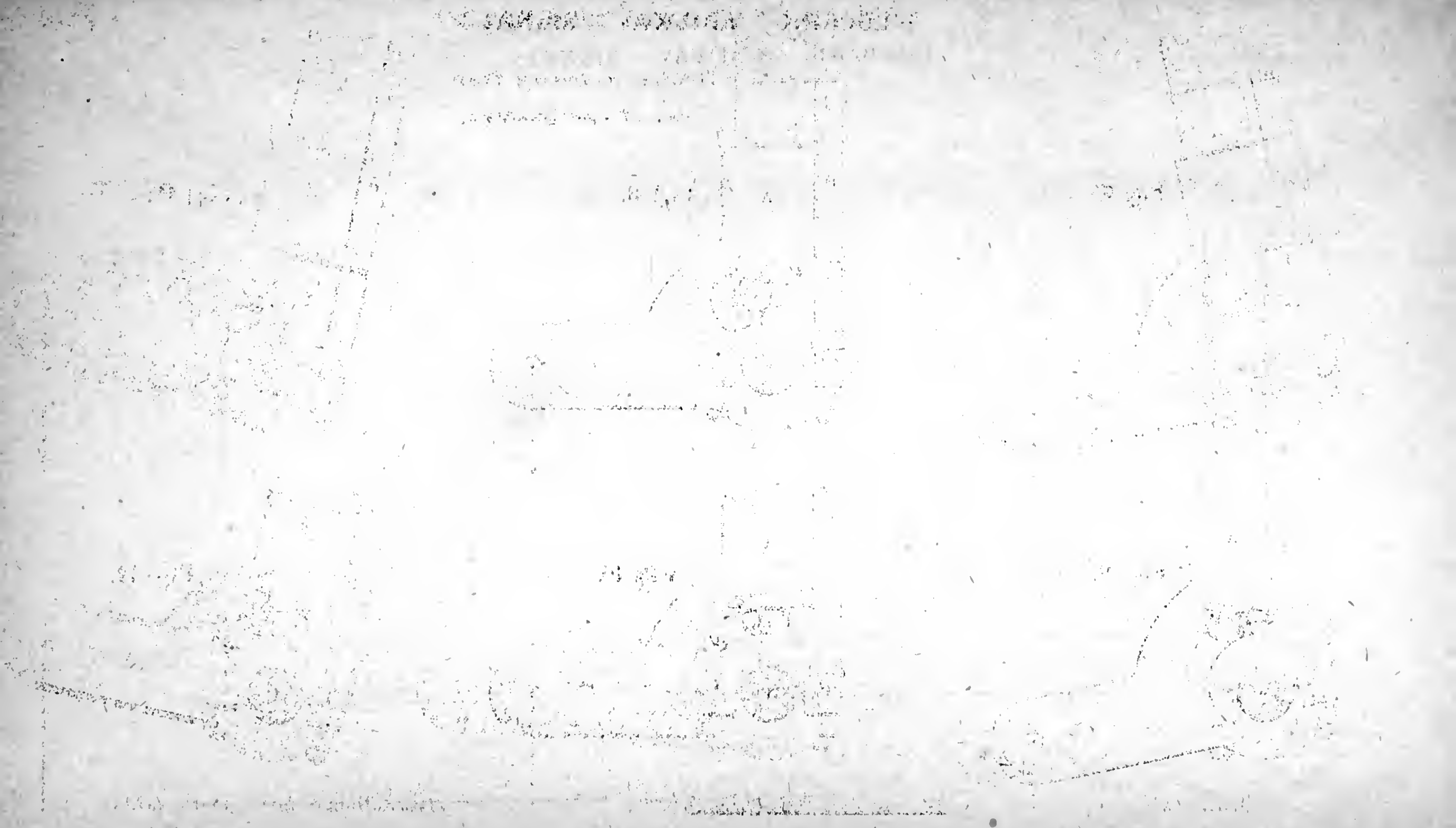


Fig. 12.

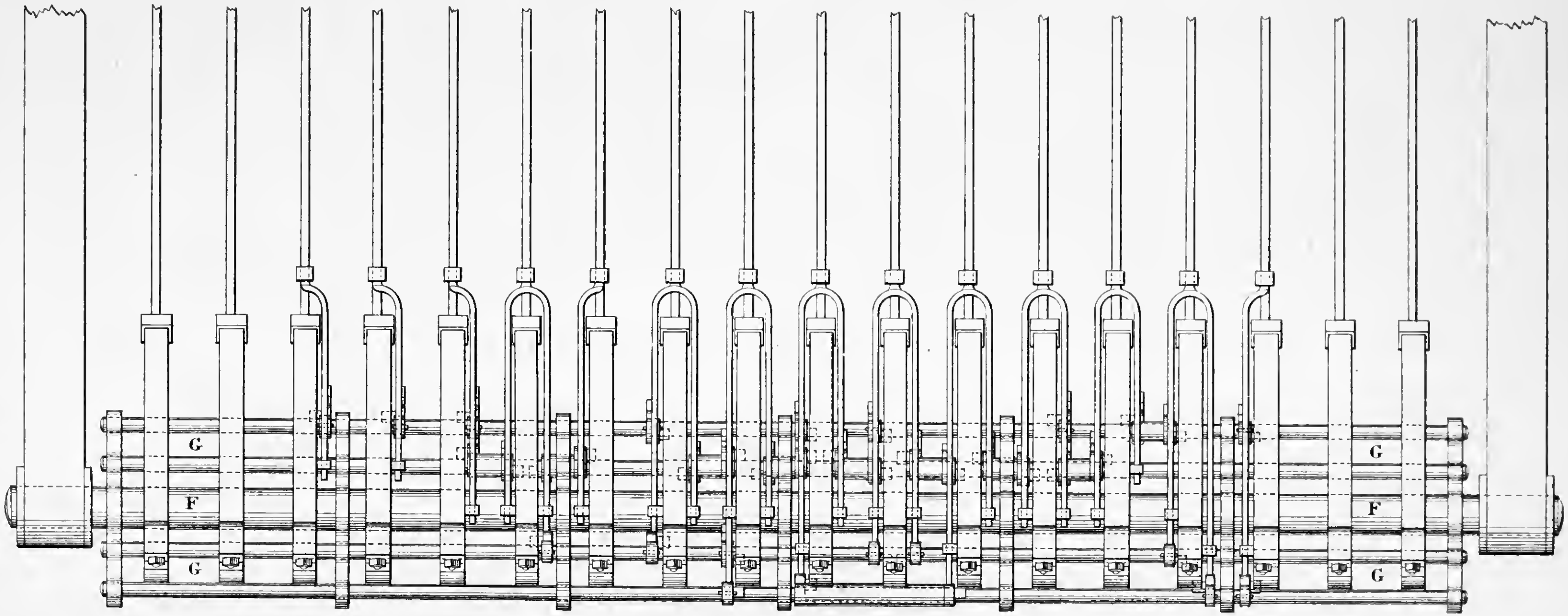
Scale 1/8th.

0 5 10 Inches.

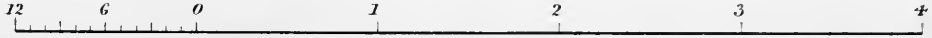


LOCKING RAILWAY SIGNALS.

Fig. 13. *Elevation of Eighteen - Lever Locking Machine.*



Scale 1/16 th.



(Proceedings Inst. M. E. 1873.)

LOCKING RAILWAY SIGNALS.

Details of Locking Gear.

Eighteen - Lever Machine.

Fig. 14.

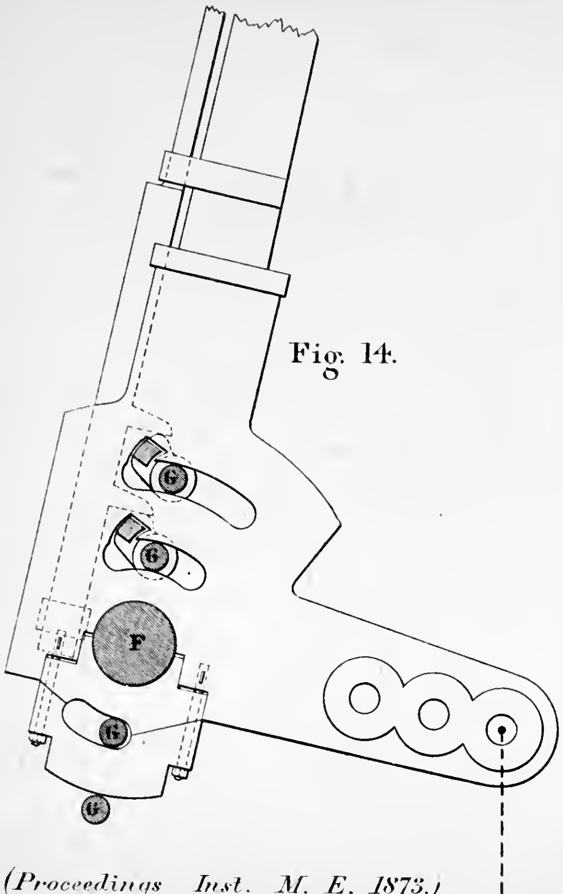


Fig. 15.

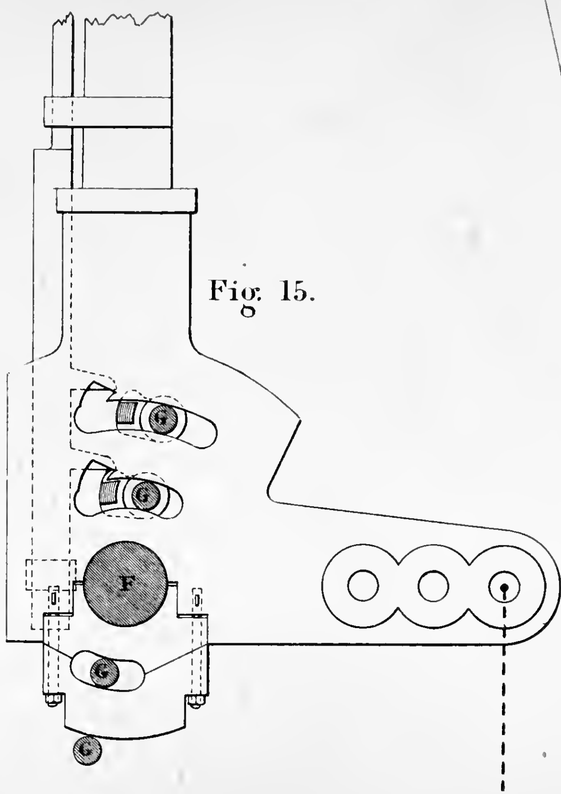
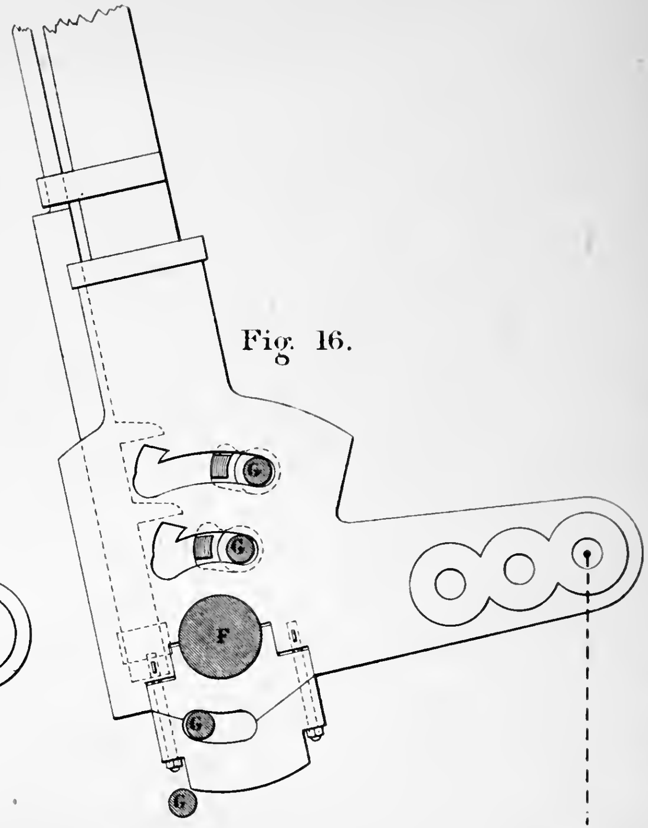
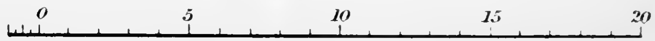


Fig. 16.



Scale 1/8 th



(Proceedings Inst. M. E. 1873.)

LOCKING RAILWAY SIGNALS.

Details of Locking Gear.

Eighteen - Lever Machine.

Fig. 17.

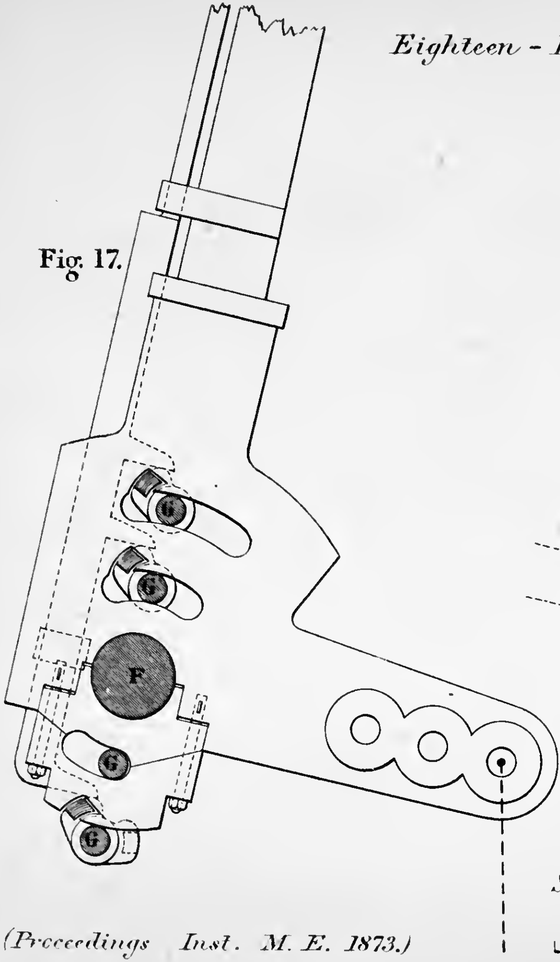


Fig. 18.

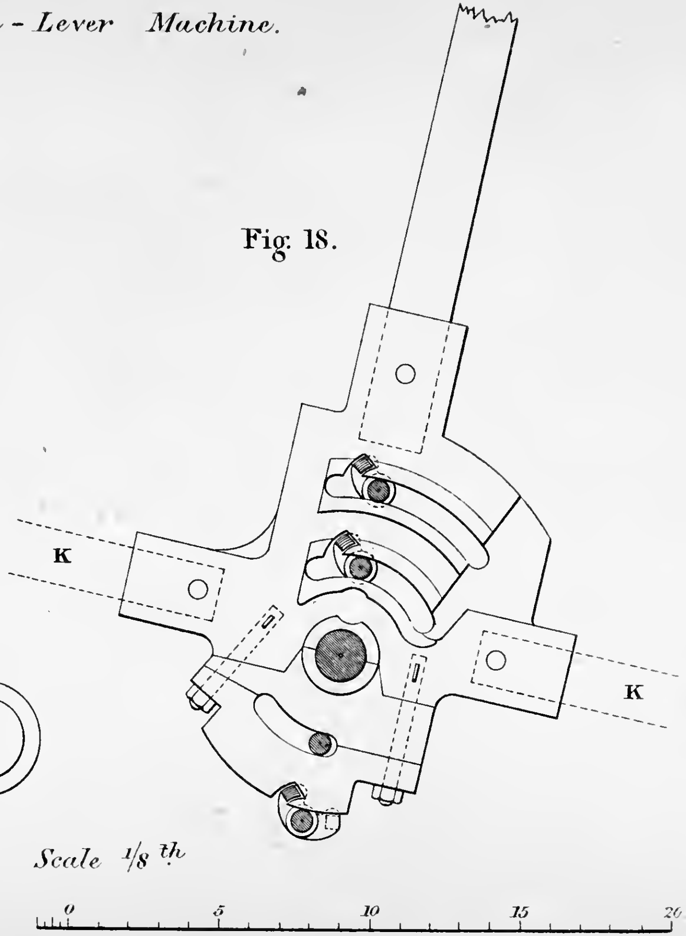


Fig. 19. *End Elevation of Rocker.*

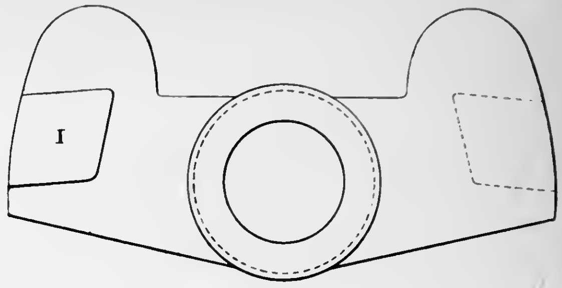
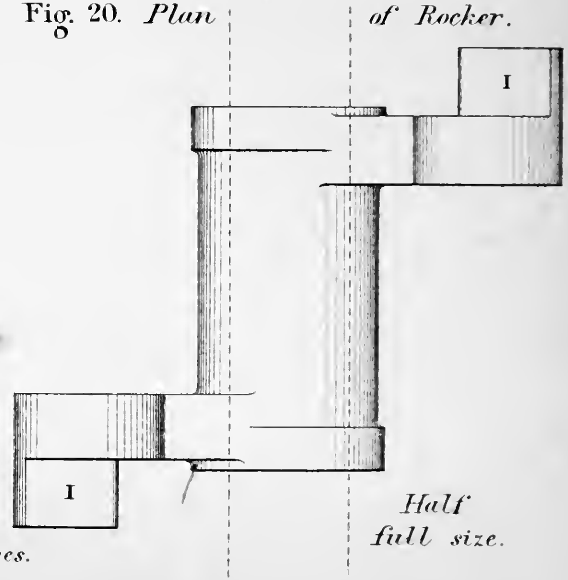


Fig. 20. *Plan of Rocker.*



Half full size.

(Proceedings Inst. M. E. 1873.)

Self-Acting Compensating Apparatus for variation of length in distant-signal wires.

Fig. 21. *Plan.*

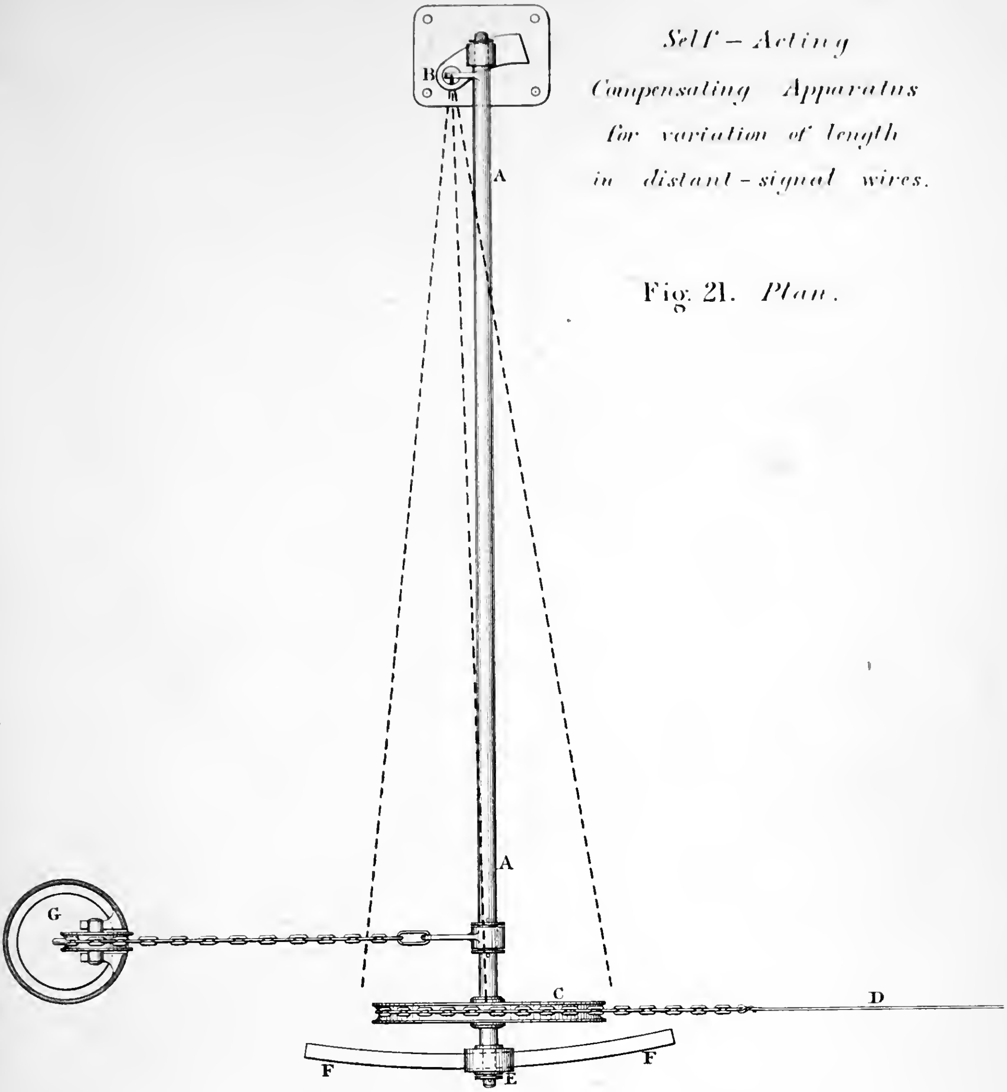
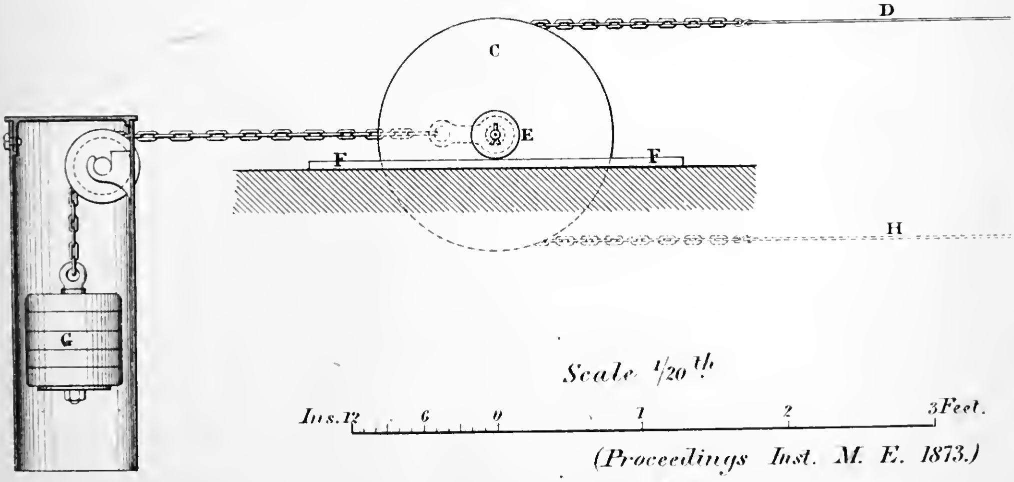


Fig. 22. *Elevation.*



Scale 1/20th

Ins. 12 6 0 1 2 3 Feet.

(Proceedings Inst. M. E. 1873.)

Self-Acting Compensating Apparatus for near signals.

Fig. 23. *Plan.*

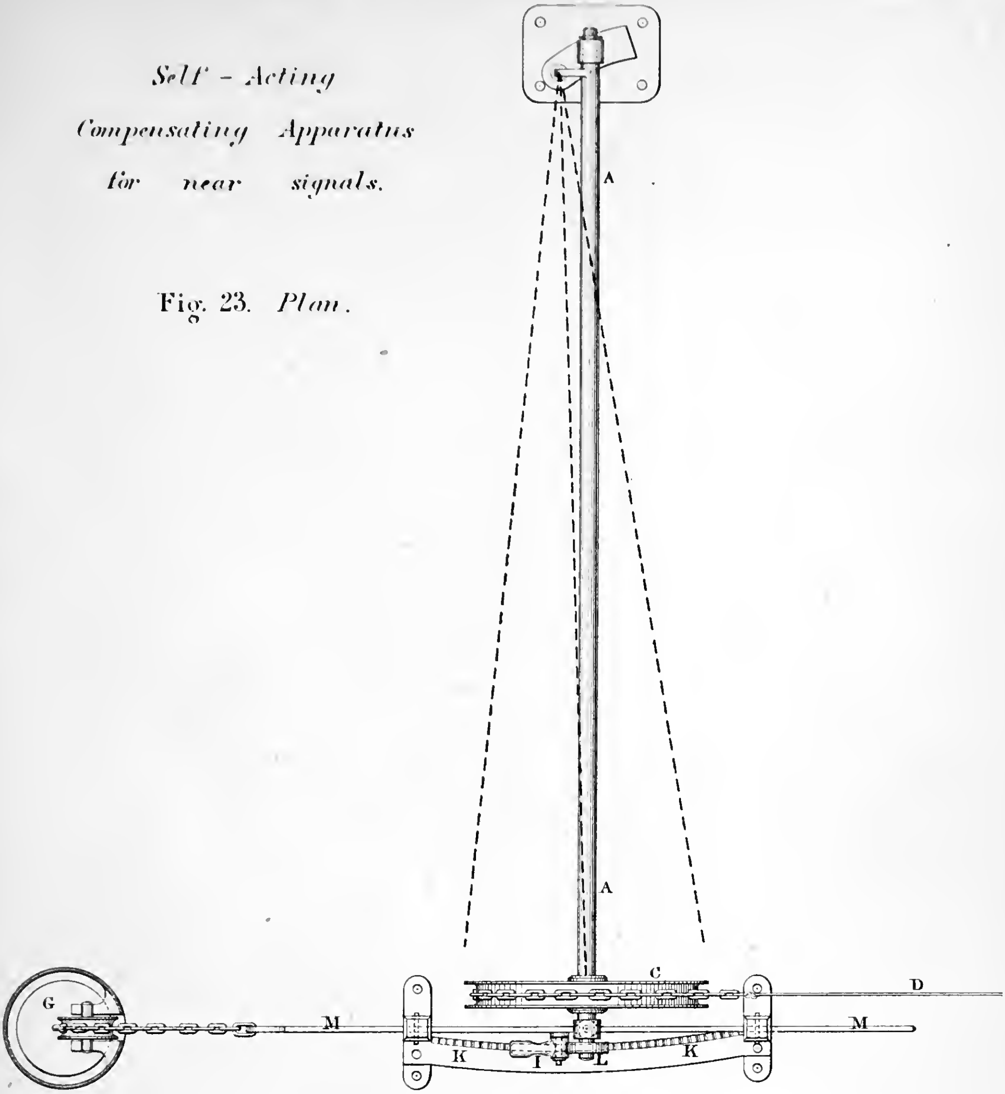


Fig. 24. *Elevation.*

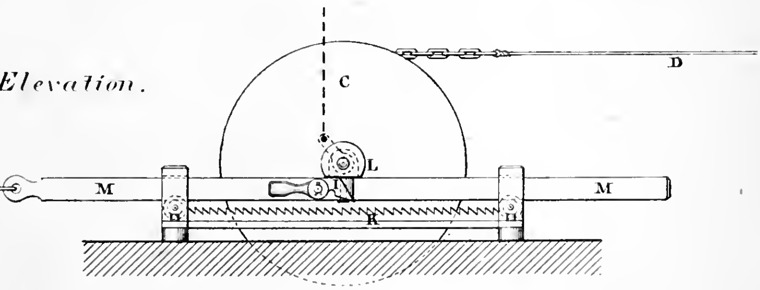
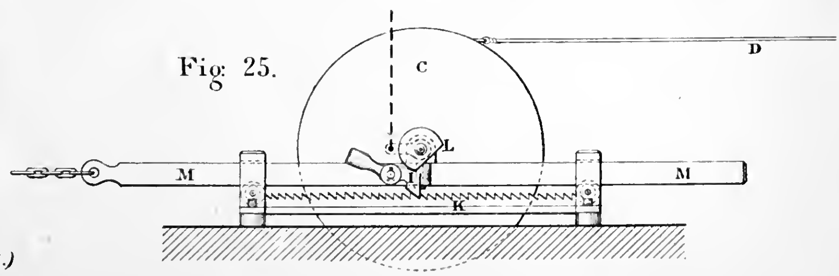


Fig. 25.



(Proceedings Inst. M.E. 1873.)

Scale 1/20th

Ins. 12 6 0 1 2 3 *Feet.*

PROCEEDINGS.

23 January, 1873.

The Twenty-sixth Anniversary Meeting of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 23rd January, 1873; C. William Siemens, Esq., D.C.L., F.R.S., President, in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The following Annual Report of the Council was then read :—

ANNUAL REPORT OF THE COUNCIL.

1873.

The Council on this occasion of the Twenty-sixth Anniversary present to the Members the annual statement of the position of the Institution and the progress during the past year.

The Financial statement of the affairs of the Institution for the year is satisfactory, showing that the balance on 31st December 1872 was £8168 16*s.* 5*d.*, after payment of the accounts due to that date. The greater portion of this balance is invested in £6000 London and North Western Railway 4 per cent. Debenture Stock, and £1000 Midland Railway 4 per cent. Debenture Stock, registered in the names of Mr. John Ramsbottom, Mr. Frederick J. Bramwell, and Mr. Sampson Lloyd, as interim trustees on behalf of the Institution. The Finance Committee have examined and checked the receipts and payments of the Institution for last year 1872, and report that the following Abstract of Receipts and Expenditure rendered by the Treasurer is correct. (*See Abstract appended.*)

The total number of Members of all classes in the Institution for last year is 912, of whom 4 are Honorary Life Members, 31 are Associates, and 24 are Graduates; 55 of the whole are resident in various foreign countries.

The following deceases of Members of the Institution have occurred during the past year 1872:—

Martin Baldwin, ...	Bilston.
Charles Bladen, ...	Glasgow.
Robert Jobson, ...	Dudley.
John Laybourne, ...	Newport, Mon.
William Anthony Matthews, ...	Sheffield.
John Platt, M.P., ...	Oldham.
William John Macquorn Rankine, . . .	Glasgow.
Edward Scott, ...	Manchester.

The following Donations to the Library of the Institution have been received during the past year, for which the Council have the pleasure of expressing their thanks to the Donors. They trust the Members generally will promote the formation of a good collection of Engineering Books, Drawings, and Models or Specimens of interest in the Institution, for the purpose of reference by the Members personally or by correspondence; and Members are requested to present copies of their Works to the Library of the Institution.

LIST OF DONATIONS TO THE LIBRARY.

On Fluid Compressed Steel, and Rifled Guns, by Sir Joseph Whitworth, Bart.; from the author.

On the Strength of Materials and Structures, by John Anderson; from the author.

Iron as a Material of Construction, by William Pole; from the author.

Theatrum Machinarum Novum, by G. A. Böcklern, printed in Nürnberg in 1673; from Mr. William Hopper.

Fabrication des Projectiles de l'Artillerie, by M. S. Jordan; from the author.

On the Mathematical Theory of Stream-Lines, especially those with four foci and upwards, by Professor Rankine; from the author.

New Formulas for the Loads and Deflections of Solid Beams and Girders, by William Donaldson; from the author.

On the Scroll Drum, by George Fowler; from the author.

On the Newport Puddling Furnace, by Jeremiah Head; from the author.

On the Bridge over the Gorai River, by Bradford Leslie; from the author.

Notes on the Chemical Geology of the Goldfields of California, by J. Arthur Phillips; from the author.

Description of Janicki's Floating Dock, by Henry Simon; from the author.

On the Steam Boiler, by Joseph Harrison, Jun.; from the author.

On Asbestos, and its use as Steam-engine Packing, by St. John V. Day; from the author.

On the Early Use of Iron, by St. John V. Day; from the author.

Inaugural Address to the Institution of Civil Engineers of Ireland, by the President, Mr. Bindon B. Stoney; from the author.

Lectures on Sanitary Engineering, by Baldwin Latham; from the School of Military Engineering, Chatham.

Lectures on Railways and Railway Signalling, &c., by Capt. Tyler; from the School of Military Engineering.

Lectures on Building Materials, by W. Y. Dent; from the School of Military Engineering.

Lectures on Canals, Reservoir Dams, &c., by Russel Aitken; from the School of Military Engineering.

On Railway Amalgamation, by B. Haughton; from the author.

Report of the Miners' Association of Cornwall and Devonshire; from Mr. J. H. Collins.

Scales for ready comparison of British and Metric Weights and Measures, by A. L. Newdigate; from the author.

A British Decimal System of Weights and Measures, described by Abacus.

On Retail Traders and Co-operative Stores, by Jeremiah Head; from the author.

Recollections of Canada, by Lieut. Carlile, R.A., and Lt.-Col. Martindale, C.B., R.E.; from Lt.-Col. Martindale.

Catalogue of Victorian Patents and Abstracts of Specifications; from the Victorian Government.

Annual Report of the Commissioner of Agriculture and Arts for Ontario for 1871, and Map of Ontario; from the Commissioner.

Proceedings of the Institution of Civil Engineers; from the Institution.

Proceedings of the French Institution of Civil Engineers; from the Institution.

Report of the British Association for the Advancement of Science; from the Association.

Transactions of the North of England Institute of Mining Engineers; from the Institute.

Proceedings of the South Wales Institute of Engineers; from the Institute.

Transactions of the Institution of Engineers in Scotland; from the Institution.

Transactions of the Institution of Civil Engineers of Ireland; from the Institution.

Transactions of the Institution of Naval Architects, 13 vols. from the commencement in 1860; from the Institution.
Journal of the Iron and Steel Institute; from the Institute.
Transactions of the Society of Engineers, 1869 and 1870; from the Society.
Journal of the Society of Telegraph Engineers; from the Society.
Professional Papers of the Corps of Royal Engineers; from the Royal Engineer Establishment.
Journal of the Hannover Architect and Engineer's Society; from the Society.
Journal of the French Society for the Encouragement of National Industry; from the Society.
Journal of the Saxon Society of Engineers; from the Society.
Transactions of the American Society of Civil Engineers; from the Society.
Proceedings of the Cleveland Institution of Engineers; from the Institution.
Transactions of the Chesterfield and Derbyshire Institute of Engineers; from the Institute.
Proceedings of the Royal Artillery Institution; from the Institution.
Journal of the Royal United Service Institution; from the Institution.
Transactions of the Institution of Surveyors; from the Institution.
Proceedings of the Royal Institution of Great Britain; from the Institution.
Proceedings of the Philosophical Society of Glasgow; from the Society.
Report of the Royal Cornwall Polytechnic Society; from the Society.
Journal of the Norwegian Polytechnic Society; from the Society.
Report of the Smithsonian Institution for 1870; from the Institution.
Proceedings and Journal of the Asiatic Society of Bengal; from the Society.
Memoirs of the Literary and Philosophical Society of Manchester; from the Society.
Journal of the Liverpool Polytechnic Society; from the Society.
Reports of the Manchester Association for the Prevention of Steam Boiler Explosions; from Mr. Lavington E. Fletcher.
Report of the Manchester Boiler Insurance Company; from Mr. Robert B. Longridge.
Reports of the Midland Steam Boiler Association; from Mr. Edward B. Marten.
Report of the National Boiler Insurance Company; from Mr. Henry Hiller.
Journal of the Society of Arts; from the Society.
Beeton's Dictionary of Information in Science, Art, and Literature; from the Editor.
The Engineer; from the Editor.
Engineering; from the Editor.
The Mechanics' Magazine; from the Editor.
The Mining Journal; from the Editor.
The Railway Record; from the Editor.

The Papers brought before the meetings during the past year, and the discussions that took place upon them, have possessed much practical interest, and form a valuable addition to the Proceedings of the Institution. The Council request the aid and co-operation of the Members in carrying out the objects of the Institution and maintaining its advanced position, by contributing Papers on Engineering subjects that have come under their observation, and communicating the particulars and results of executed works and practical experiments that may be serviceable and interesting to the Members; and they invite communications upon the subjects in the list appended and other subjects advantageous to the Institution.

The following Papers have been read at the Meetings during the past year:—

Description of the Disintegrating Flour Mill and Machine for Pulverising minerals &c., without grinding, crushing, or stamping; by Mr. Thomas Carr, of Bristol.

On the Strength and Proportions of Riveted Joints, with the results of some recent experiments; by Mr. Walter R. Browne, of Bristol.

On a Steam Jet for exhausting air &c., and the results of its application; by the President.

On the progress effected in Economy of Fuel in Steam Navigation, considered in relation to Compound-Cylinder Engines and High-Pressure Steam; by Mr. Frederick J. Bramwell, of London.

On the application of Water Pressure to Shop Tools and Mechanical Engineering Work; by Mr. Ralph Hart Tweddell, of London.

Description of a Coal Cutting Machine with rotary cutter, worked by compressed air; by Mr. Robert Winstanley, of Manchester.

On the Buchholz process of Decorticating Grain, and making Semolina and Flour by means of Fluted Metal Rollers; by Mr. W. Proctor Baker, of Bristol.

On the Ejector Condenser for steam engines, dispensing with an air-pump; by Mr. Alexander Morton, of Glasgow.

On the Working of the improved Compound-Cylinder Blowing Engines and Howard Boilers, at the Lackenby Iron Works, Middlesbrough; by Mr. Alfred C. Hill, of Middlesbrough.

On an improved construction of Tool for Turning metals at increased speed; by Colonel Clay, of Liverpool.

The Annual Meeting of the Institution last summer was held in Liverpool, and the Council have great pleasure in expressing their special thanks to the Local Committee, and the Chairman, Colonel Clay, and the Honorary Local Secretary, Mr. Daniel R. Ratcliff, for the very excellent arrangements and the cordial and handsome reception given to the Members on the occasion; and also their thanks to the proprietors of the works that were so liberally thrown open for the inspection of the Members; and to the railway authorities for the special arrangements granted for the excursions. The Council refer with great satisfaction to the advantages arising from these Annual Meetings of the Institution in different localities, in consequence of the opportunities for visiting important Engineering Works on those occasions, and the facilities afforded for the personal communication of the Members in different districts.

The Council have considered carefully the proposal to hold one of the ordinary meetings of the Institution each year in London, and have come to the conclusion to recommend a trial of such a meeting to be made in the present year by holding the next Spring meeting in London; and the requisite alteration in the Rules will be proposed accordingly at the present Anniversary Meeting.

The Council have had under consideration for some time the importance and desirability of having a suitable house for the Institution, as soon as the funds were sufficient to warrant such a step; and considering the time had arrived when, if approved by the Members, steps might be taken for erecting a suitable building for the seat of business of the Institution, the Council have come to the conclusion to ask the opinion of all the Members whether such a house should be built and if so in what locality; and the requisite authority to enable them to obtain the opinion of the Members will be applied for at the present Anniversary Meeting.

The President, Vice-Presidents, and five of the Members of the Council in rotation, go out of office this day, according to the

rules of the Institution; and the ballot taken at the present Meeting will show the election of the Officers and Council for the ensuing year.

SUBJECTS FOR PAPERS.

Steam Engine Boilers, particulars of construction—form and extent of heating surface—relative value of radiant surface and flue surface in effect and economy—cost—consumption of fuel—evaporation of water—pressure of steam—density and heat of steam—superheated steam, simple or mixed with common steam—combined air and steam—safety valves—water gauges—explosion of boilers, and means of prevention—strength and proportions of riveted joints, single and double riveting—comparative strength of drilled and punched plates—effects of heat on the metal of boilers, low-pressure and high-pressure—steel boilers—cast-iron boilers—welded boilers—small water-space boilers—incrustation of boilers, and means of prevention—corrosion of boilers, and means of prevention—effects of surface condensers on the metal of boilers—evaporative power and economy of different kinds of fuel; coal, wood, charcoal, peat, coke, and artificial fuel—mechanical firing, moveable grates, and smoke-consuming apparatus, facts to show the best plan, and results of working—plans for heating feed-water—mode of feeding—use of injector—circulation of water—self-acting feeding apparatus.

Steam Engines—expansive force of steam, and best means of using it—power obtained by various plans—comparison of double and single-cylinder engines—combined engines—compound-cylinder engines—comparative advantages of direct-acting and beam engines—horizontal and vertical, condensing and non-condensing engines—construction and particulars of working of injection and surface condensers—ejector condenser—air-pumps—governors—throttle valves—bearings, &c.—improved expansion gear—indicator diagrams from engines, with details of useful effect, consumption of fuel, &c.—contributions of indicator diagrams for reference in the Institution.

Pumping Engines, particulars of various constructions—Cornish engines, beam engines with crank and flywheel, direct-acting engines with and without flywheel—size of steam cylinder and degree of expansion—number and size of pumps, and strokes per minute—speed of piston—pressure upon pump—effective horse power and duty—comparison of double-acting and single-acting pumping engines—construction of pumps—plunger pumps—bucket pumps—details of different pump valves—india-rubber valves, durability and results of working—diagrams of lift of valves—application of pumps—fen-draining engines—comparative advantages of scoop wheels and centrifugal pumps, lifting trough, &c.—sewage pumping engines—details of pit work of pumping engines in mines.

Blast Engines, best kind of engine—details of construction—pressure of blast, and means of regulation—construction of valves—improvements in blast cylinders—rotary blowing machines—indicator diagrams from steam cylinder, blast cylinder, and blast main.

Marine Engines, power of engines in proportion to tonnage—different constructions of engines, compound-cylinder engines, trunk engines, oscillating engines—three-cylinder engines—use of steam jackets—dynamical effect compared with indicator diagrams—comparative economy and durability of different boilers, tubular boilers, flat-flue boilers, &c.—brine pumps, and means of preventing deposit—salinometers—weight of machinery and boilers—kind of paddle wheels—speed obtained in different steamers, with particulars of construction of engines—screw propellers, particulars of different kinds, improvements in form and position, number of arms, material, means for unshipping, bearings, horse power applied, speed obtained, section of vessel—reaction propellers—governors and storm governors.

Rotary Engines, particulars of construction and practical application—details of results of working.

Locomotive Engines, particulars of construction, details of experiments, and results of working—economy of fuel—relative value and evaporative duty of coke and coal—consumption of smoke—use of wood—construction of spark arresters—heating surface, length and diameter of tubes—material of tubes—experiments on size of tubes and blast-pipe—construction of pistons, valves, expansion gear, &c.—balanced slide-valves—indicator diagrams—expenses of working and repairs—means of supplying water to tenders—locomotives for steep gradients and sharp curves—steam breaks, counterpressure steam break—distribution of weight on wheels.

Agricultural Engines, details of construction and results of working—duty obtained—application of machinery and steam power to agricultural purposes—barn machinery—field implements—traction engines, particulars

of performance and cost of work done—steam road rollers, particulars and results.

Hot-air Engines—engines worked by gas, or explosive compounds—electro-magnetic engines—particulars and results.

Hydraulic Engines, particulars of application and working—pressure of water—construction and arrangement of valves, relief valves—construction of joints—hydraulic rams.

Water Wheels, particulars of construction and dimensions—form and depth of buckets—head of water, velocity, percentage of power obtained—turbines, construction and practical application, power obtained, comparative effect and economy—transmission of power to distant points.

Wind Mills, particulars of construction—number of sails, surface and form of sails—velocity, and power obtained—average number of days' work per annum.

Corn Mills, particulars of improvements—power employed—application of steam power—results of working with an air blast and ring stones—crushing by rolls before grinding—stone-dressing machinery.

Sugar Mills, particulars of construction and working—results of application of the hydraulic press in place of rolls—application of steam and water for extracting the last portion of saccharine matter—construction and working of evaporating pans.

Oil Mills, facts relating to construction and working, by stampers, by screw presses, and by hydraulic presses—particulars of crushing rollers and edge stones.

Cotton Mills, information respecting the construction and arrangement of the machinery—power employed, and application of power—cotton presses, mode of construction and working, power employed—improvements in spinning, carding, and winding machinery, &c.

Calico-Printing and Bleaching Machinery, particulars of improvements.

Wool Machinery, carding, combing, roving, spinning, &c.

Flax Machinery, manufacture of flax, china grass, and other fibrous materials, both in the natural length of staple and when cut.

Weaving Machinery, for manufacture of different materials—improvements in looms, &c.

Knitting Machinery, worked by hand or by power—particulars of improvements.

Rope-Making Machinery—hemp and wire ropes, comparative strength, durability, and cost—steel wire ropes—transmission of power by ropes, percentage of loss, distance, wear of ropes, &c.

Saw Mills, particulars of construction—mode of driving—power employed—particulars of work done—best speeds for vertical and circular saws—form of saw teeth—saw mills for cutting ship timbers—veneer saws—endless band saws.

Wood-Working Machines, morticing, dovetailing, planing, rounding, and surfacing—copying machinery.

Glass Machinery—manufacture of plate and sheet glass—grinding and polishing machinery—construction of heating furnaces, annealing kilns, &c.

Lathes, Planing, Boring, Drilling, Slotting, and Shaping Machines, &c., particulars of improvements—description of new self-acting tools—engineers' tools—files and file-cutting machinery.

Rolling Mills, improvements in machinery for making iron and steel—mode of applying power—use of steam hammers—piling of iron—plates—fancy sections—arrangement and speed of rolls—length of bar rolled—manufacture of rolled girders—rolling of armour plates—reversing rolling mills.

Steam Hammers, improvements in construction and application—friction hammers—air hammers.

Riveting, Punching, and Shearing Machines, worked by steam or hydraulic pressure—direct-acting and lever machines—portable machines—rivet-making machines—comparative strength of hand and machine riveting.

Stamping and Coining Machinery, particulars of improvements, &c.

Locks, and lock-making machinery—iron safes.

Paper-Making and Paper-Cutting Machines, new materials and results.

Printing Machines, particulars of improvements, &c.—machines for printing from engraved surfaces—type composing and distributing machines.

Water Pumps, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

Air Pumps, facts relating to the best construction, means of working, and application—velocity of piston—construction, lift, and area of valves.

Hydraulic Presses, facts relating to the best construction, means of working, and application—economical limit of pressure.

Rotary and Centrifugal Pumps, ditto ditto ditto.

Fire Engines, hand and steam, ditto ditto ditto.

Sluices and Sluice Cocks, worked by hand or hydraulic power, ditto.

Cranes—steam, hydraulic, and pneumatic cranes—travelling cranes.

Lifts for raising railway wagons—hoists for warehouses, blast-furnaces, &c.—safety apparatus.

Toothed Wheels, best construction and form of teeth—results of working—strength of iron and wood teeth—moulding by machinery.

Driving Belts and Straps, best make and material, leather, gutta-percha, vulcanised india-rubber, rope, wire, chain, &c.—comparative durability, and results of working—power communicated by certain sizes—frictional gearing, construction and driving power obtained—friction clutches—shafting and couplings.

DYNAMOMETERS, construction, application, and results of working.

PRESSURE GAUGES, for steam and water—varieties of construction—durability and results of working.

DECIMAL MEASUREMENT—application of decimal system of measurement to mechanical engineering work, drawing and construction of machinery, manufactures, &c.—construction of measuring instruments, gauges, &c.

STRENGTH OF MATERIALS, facts relating to experiments, and general details of testing.

GIRDERS OF CAST AND WROUGHT IRON, particulars of different constructions, and experiments on them—rolled girders—best forms and proportions of girders for different purposes—best mixture of metal—mixtures of wrought iron with cast.

DURABILITY OF TIMBER of various kinds—best plans for seasoning and preserving timber and cordage—results of various processes—comparative durability of timber in different situations—experiments on actual strength of timber.

CORROSION OF METALS by salt and fresh water, and by the atmosphere, &c.—facts relating to corrosion, and best means of prevention—means of keeping ships' bottoms clean—galvanic action, nature and preventives.

ALLOYS OF METALS, facts relating to different alloys.

FRICTION OF VARIOUS BODIES, facts relating to friction under ordinary circumstances—facts on increase of friction by reduction of surface in contact—friction of iron, brass, copper, tin, wood, &c.—proportion of weight to rubbing surface—best forms of journals, and construction of axleboxes—wood bearings—water axleboxes—lubrication, best materials, means of application, and results of practical trials—best plans for oil tests—friction breaks.

IRON ROOFS, particulars of construction for different purposes—durability in various climates and situations—comparative cost, weight, and durability—roofs for slips of cast-iron, wrought-iron, timber, &c.—best construction, form, and materials—details of large roofs, and cost.

FIRE-PROOF BUILDINGS, particulars of construction—most efficient plan—results of trials.

CHIMNEY STACKS of large size—particulars, form, mode of building, cheapest construction, &c.—force of draught, and temperature of current.

BRICKS, manufacture, durability, and strength—hollow bricks, fire bricks, and fire clay—perforated bricks, cost of manufacture, and advantages—dry-clay bricks—machines for brick-making—burning of bricks.

GAS WORKS, best form, size, and material for retorts—construction of retort ovens—quantity and quality of gas from different coals—oil gas, cheapest mode of making—water gas, &c.—improvements in purifiers, condensers, and gasholders—wet and dry gas-meters—self-regulating meters—pressure

of gas, gas exhauster—gas pipes, strength and durability, and construction of joints—proportionate diameter and length of gas mains, and velocity of the passage of gas—experiments on ditto, and on the friction of gas in mains, and loss of pressure—lighting railway trains with gas.

WATER WORKS, facts relating to water works—application of power, and economy of working—proportionate diameter and length of pipes—experiments on the discharge of water from pipes, and friction through pipes—strength and durability of pipes and construction of joints—penetration of frost in different climates—relative advantages of stand pipes and air vessels—sluices and self-acting valves—relief valves—machinery for working sluices—water meters, construction and working.

WELL SINKING AND ARTESIAN WELLS, facts relating to—boring tools, construction and mode of using.

TUNNELLING MACHINES, particulars of construction, and results of working.

COFFERDAMS AND PILING, facts relating to construction—cast-iron sheet piling.

PIERS, fixed and floating, and pontoons—particulars of construction.

PILE DRIVING APPARATUS, particulars of improvements—use of steam power—particulars of working—weight of ram and height of fall, total number of blows required—vacuum piles—compressed air system—screw piles—pile shoes.

DREDGING MACHINES, particulars of improvements—application of dredging machines—power required and work done.

DIVING BELLS AND DIVING DRESSES, facts relating to the best construction.

LIGHTHOUSES, cast-iron and wrought-iron, ditto ditto.

SHIPS, iron and wood—details of construction—lines, tonnage, cost per ton—water ballast—steel masts and yards, and wire-rope rigging—comparative strength and advantage of iron and wood ships—arrangements for docking and repairing ships—steering gear—application of steam and hydraulic power to steering.

GUNS, cast-iron, wrought-iron, and steel—manufacture and proof—rifling—manufacture of shot and shells.

SMALL ARMS, machinery for manufacture of rifles and cartridges, &c.—breech-loading mechanism.

BLASTING, facts relating to blasting under water, and blasting generally—use of gun-cotton, &c.—effects produced by large and small charges of powder—arrangement of charges.

MINING OPERATIONS, facts relating to mining—modes of working and proportionate yield—coal-cutting machines—means of ventilating mines—use of ventilating machinery—safety lamps—lighting mines by gas—drainage of mines—sinking pits—mode of raising materials—safety guides—winding machinery—hauling arrangements underground and at surface—stone-breaking machines—mode of breaking, pulverising, and dressing various descriptions of ores—coal-washing machinery.

Blast Furnaces, shape and size—consumption of fuel—yield and quality of metal—pressure of blast—economy of working—improvements in manufacture of iron—comparative results of hot and cold blast—increased temperature of blast—construction and working of hot-blast stoves—pyrometers—construction of tuyeres—means and results of application of waste gas from close-topped and open-topped furnaces—preparation of materials for furnace and mode of charging.

Puddling Furnaces, best forms and construction—worked with coal, charcoal, &c.—application of machinery to puddling.

Smelting Furnaces, for reduction of copper, tin, and lead ores, &c.—best construction and modes of working.

Heating Furnaces, best construction—consumption of fuel, and heat obtained.

Cupolas, construction and proportions—improvements in means of blowing—results of working, and economy of fuel.

Converting Furnaces, construction of furnaces—manufacture of steel—casehardening, &c.—converting materials employed.

Smiths' Forges, best construction—size and material—power of blast—hot blast, &c.—construction of tuyeres.

Blowing Fans, best construction, form of blades, &c.—facts relating to power employed and percentage of effect produced—pressure and quantity of air discharged—size and construction of air mains—mechanical ventilation and warming of public buildings.

Coke and Charcoal, particulars of the best mode of making, and construction of ovens, &c.—open coking, mixtures of coal-slack and other materials—evaporative power of different varieties—peat, manufacture of compressed peat.

Railways, construction of permanent way—section of rails, and mode of manufacture—mode of testing rails—experiments on rails, deflection, deterioration, and comparative durability—material and form of sleepers, size, and distances—improvements in chairs, keys, and joint fastenings—permanent way for hot climates.

Switches and Crossings, particulars of improvements, and results of working.

Turntables, particulars of various constructions and improvements—engine turntables.

Signals for stations and trains, and self-acting signals—self-acting locking apparatus.

Electric Telegraphs, improvements in construction and insulation—coating of wires—underground and submarine cables—mode of laying, and machinery employed.

Railway Carriages and Wagons, details of construction—proportion of dead weight.

BREAKS for carriages and wagons, best construction—self-acting breaks—continuous breaks—steam and hydraulic breaks.

BUFFERS for carriages, &c., and station buffers—different constructions and materials.

COUPLINGS for carriages and wagons—safety couplings.

SPRINGS for carriages, &c.—buffing, bearing, and draw springs—range, and deflection per ton—particulars of different constructions and materials, and results of working.

RAILWAY WHEELS, wrought-iron, cast-iron, and wood—particulars of different constructions, and results of working—comparative expense and durability—wrought-iron and steel tyres, comparative economy and results of working—mode of fixing tyres—manufacture of weldless tyres, and solid wrought-iron wheels.

RAILWAY AXLES, best description, form, material, and mode of manufacture.

PREPARATION OF PAPERS.

The Papers to be written in the third person, on foolscap paper, on one side only of each page, leaving a clear margin of an inch width on the left side. In the subjects of the papers, extracts from printed publications and questions of patent right or priority of invention are not admissible.

The Diagrams to be on a large scale and strongly coloured, so as to be clearly visible to the meeting at the time of reading the paper. Enlarged details to be added for the illustration of any particular portions, drawn full size or magnified, with the different parts strongly coloured in distinctive colours. Several explanatory diagrams drawn roughly to a large scale in dark pencil lines and strongly coloured are preferable to a few small-scale finished drawings. The scale of each diagram to be marked upon it.

INSTITUTION OF MECHANICAL ENGINEERS.

Abstract of Receipts and Expenditure.

For the year ending 31st December 1872.

Cr.		£	s.	d.
By Balance 31st Dec. 1871; Invested	5973 16 2			
In Bank	1254 2 6	7227	18	8
,, Subscriptions from 53 Members in arrear . .		159	0	0
,, do. 1 Associate in arrear . .		3	0	0
,, do. 1 Graduate in arrear . .		2	0	0
,, do. 732 Members for 1872 . .		2196	0	0
,, do. 25 Associates for 1872 . .		75	0	0
,, do. 25 Graduates for 1872 . .		50	0	0
,, do. 11 Members in advance . .		33	0	0
,, do. 1 Graduate in advance .		2	0	0
,, Entrance Fees from 69 New Members		138	0	0
,, do. 1 New Associate . . .		2	0	0
,, do. 5 New Graduates . . .		5	0	0
,, Sale of Extra Reports		8	6	0
,, Interest; From Bank	32 15 9			
On £4500 Stock at 4 p. c. 343 days	170 7 8			
,, £1500 do. at 4 p. c. one year	60 0 0			
,, £1000 do. at 4 p. c. 148 days	16 4 4	279	7	9
		£10,180	12	5

Dr.		£	s.	d.
To Printing and Engraving Reports of Proceedings	631 10 4			
Less Authors' copies of Papers, repaid	41 15 0	589	15	4
,, Stationery, Binding, Printing of Circulars, &c. .		88	19	9
,, Office Expenses, Clerks, and Petty Disbursements		70	15	1
,, Coals, Gas, and Water		21	1	6
,, Expenses of Meetings		77	7	3
,, Fittings and Repairs		1	10	3
,, Travelling Expenses		58	3	2
,, Parcels		3	19	0
,, Postages		77	8	10
,, Salaries		898	13	0
,, Insurance		2	10	0
,, Rent and Taxes		121	12	10
Balance 31st Dec. 1872; Invested	6973 16 2			
In Bank	1195 0 3	8168	16	5
		£10,180	12	5

(Signed) SAMPSON LLOYD,
CHARLES COCHRANE, } Finance Committee.
WALTER MAY,

23rd January, 1873.

MEMOIRS

OF MEMBERS DECEASED IN 1872.

Martin Baldwin was born on 22nd November 1788 at Coalbrookdale, Shropshire, his father, Mr. William Pearce Baldwin, being at that time the manager of the moulding department at the Coalbrookdale Iron Works, and afterwards at the iron works of Sir John Guest at Dowlais, Glamorganshire. In 1809 the family became permanently resident in Staffordshire, where Mr. Martin Baldwin and his brothers carried on for many years an extensive engine factory at Bradley, near Bilston. At these works he constructed some of the largest and best engines in the district, amongst which were the first two pumping engines erected for the Birmingham Water Works in 1830 at Aston; and also the large pumping engine erected in 1829 at the Moat Colliery, Tipton, from his plans selected by Mr. J. U. Rastrick, which had a cylinder of 88 inches diameter, and was in all respects the largest at that time in South Staffordshire. He constructed also many important engines for other districts and for foreign countries. In connection with his brothers he erected large tinplate works at Bradley, and the adjacent Bankfield boiler-plate, sheet-iron, and hoop mills, where he invented the present mode of shearing strong boiler plates of any length up to 7 feet at each stroke. He also carried on the Lower Bovereux Colliery and erected the blast furnaces there, for the working of which he constructed in 1851 the circular hot-blast oven described to the Institution in 1859 (see Proceedings Inst. M. E. 1859 pages 79-81). He was well known as the inventor of many improvements in the construction of engines and machinery, all of which he freely threw open to general use; and amongst other inventions due to him may be mentioned the double-seated nozzle-valve, known as the American or bell valve. In his boyhood at Dowlais, having his attention

drawn to the frequent necessity for renewing the cock then in use there for reversing the steam in the engine, he constructed in its stead a slide-valve of his own invention, which was very similar to those now in use, and without any knowledge of Murdock's slide-valve invented probably about the same time. In 1820 he cast without the aid of a pattern, by directly modelling the design in the sand, the large cast-iron column 45 feet high, which formerly stood in the market-place at Wolverhampton. Mr. Baldwin was greatly esteemed by all who knew him, and in conjunction with his family he erected a church, parsonage, and schools, close to the works at Bradley, for the benefit of his workpeople and their families. His death took place after a few days' illness on 16th February 1872 at his residence in Wolverhampton, in the eighty-fourth year of his age. He became a Member of the Institution in 1865.

Charles Bladen was born on 24th June 1829 at Wolverhampton, and learnt the trade of plate-mill roller at Messrs. Thorneycroft's works, where his father was manager. At the age of twenty-five he took the management of the rolling mills at the Shelton Bar Iron Works, North Staffordshire, where he remained ten years; after which he laid down very extensive rolling mills for Messrs. Palmer Brothers at Jarrow-on-Tyne, and was general manager there for four years. He was then engaged by Messrs. Hannay and Sons as head manager of the Blochairn Iron Works, Glasgow, and remained there for six years, during which time he enlarged the works to more than double their previous size. Having been obliged by ill health to relinquish this position, he afterwards became the practical manager of new steel works at Newton, near Glasgow; but had been there only three months when a brief illness terminated his life on 11th October 1872 in the forty-fourth year of his age. He became a Member of the Institution in 1865.

Robert Jobson was born at Sheffield on 1st April 1817. In 1833 he was engaged under Mr. John Joseph Bramah, of Grosvenor Works, London, and assisted in the construction of numerous

station works and bridges on the London and Birmingham and the North Midland Railways, superintending entirely the erection of the work, for the satisfactory carrying out of which he received the commendation of Mr. Robert Stephenson. About 1840 he commenced business as an ironfounder on his own account near Dudley, and carried out various important contracts for engineering works on a large scale, including a large portion of the castings for the Great Exhibition Building in 1851 and for the Crystal Palace. He was also the inventor of some valuable improvements in mechanical engineering, those best known being his machinery for moulding, and that for making compressed porcelain telegraph insulators; of the former of these a description was given to the Institution in 1858 (see Proceedings Inst. M. E. 1858 page 14). His death took place suddenly at his residence near Dudley on 1st August 1872, in the fifty-sixth year of his age. He became a Member of the Institution in 1847.

John Laybourne was born on 31st July 1828 at Nafferton Lodge, near Driffield, East Yorkshire, and in 1843 was apprenticed at the Hareshaw Iron Works at Hexham and Bellingham, Northumberland, where he remained until the closing of the works in 1847. He then went to Messrs. E. B. Wilson and Co., Railway Foundry, Leeds, and after passing through these works and the drawing office became in 1853 head locomotive draughtsman to Messrs. Stothert Slaughter and Co., Avonside Engine Works, Bristol. In 1857 he left these works to establish the Isca Foundry Co. at Newport, Monmouthshire, which he successfully managed to within a short period of his death. He introduced into England with success the American cast-iron boiler, upon which a paper was read to the Institution in 1871 (see Proceedings Inst. M. E. 1871 page 263). He died of heart disease at Bournemouth on 24th March 1872 at the age of forty-three. He became a Member of the Institution in 1857.

William Anthony Matthews was born on 14th August 1813 in Malta, his father being an officer in the army. At an early

age he came to Sheffield, where he resided until his death, which took place on 19th July 1872 in the fifty-ninth year of his age. For upwards of twenty-five years he was an active partner in the firm of Messrs. Thomas Turton and Sons, of the Sheaf Steel Works, which owed much of its reputation to his labours. In 1852 and 1853 he was both Mayor and Master Cutler of Sheffield, being the first to hold the two offices together. He was one of those who accompanied Mr. Cobden to Paris, as a deputation from the Chamber of Commerce, on behalf of the commercial treaty with France; and in 1862 he was a juror at the London Exhibition. During the last few years of his life he retired from business on account of ill health. He became a Member of the Institution in 1847.

John Platt, M.P. for Oldham, was born on 15th September 1817 at Dobcross, Saddleworth, Yorkshire, where his father, Mr. Henry Platt, was engaged in a small way of business as a maker of woollen machinery; but owing to the wonderful development of the cotton trade the business was removed to Oldham in 1821, where his father soon afterwards became associated with the late Mr. Elijah Hibbert under the firm of Hibbert and Platt. He received his education at Dunham Massey, and at a very early age commenced his career in the business. In 1837 he was admitted a member of the firm, under the style of Hibbert Platt and Sons, and began to take an active share in the management of the concern. In 1843, owing to the expansion of the trade through the abrogation of the laws prohibiting the exportation of machinery, the already extensive works were found to be too small, and to meet the demands of the Lancashire and Continental markets large premises and machine shops were erected at Werneth, Oldham. In 1851 Mr. Platt took a great interest in the International Exhibition of that year, to which his firm contributed an extensive series of working machinery illustrating the process of preparing, spinning, and weaving cotton, forming an important feature in the Exhibition; their machinery became still more extensively employed, and further development of the works was rendered necessary. In 1854 Mr. John Platt and

his brother the late Mr. James Platt, M.P., in consequence of the death of the senior partners, took in other partners under the style of Platt Brothers and Co., which was retained till the incorporation of the firm as a limited company in 1867 with Mr. Platt as chairman. To the manufacture of cotton machinery was added that of woollen and worsted machinery, and large iron forges and rolling mills were erected to meet the requirements of the works, and an extensive brick-making business was also established. A further demand was made upon Mr. Platt's energy during the American Cotton famine, which created an immediate necessity for an improved construction of cotton gins; and the development of this new branch of business was so rapid that before the close of the war the works were turning out about 250 of these machines per week; the number of hands now employed exceeds 6000 men. To Mr. Platt's influence as an engineer and a large employer of labour, and to his untiring energy, the commercial prosperity of Oldham is mainly due; he took the deepest interest in all that was connected with its welfare, and the extension of the railway system as well as the acquisition of an abundant water supply is in a great measure to be attributed to him. He also greatly promoted the educational advancement of the borough by founding the Schools of Science and Art in connection with the Oldham Lyceum, and by contributing largely to the support of both institutions. His long business experience and great administrative ability brought him necessarily into prominence in connection with most of the leading commercial questions of the day; and in the House of Commons he will long be remembered as one of the best authorities in matters connected with the industries of Lancashire. He entered Parliament in 1865 as member for Oldham, and retained his seat till his death, which took place on 18th May 1872 in the fifty-fifth year of his age, in Paris, where he was seized with an attack of typhoid fever while returning to England from a continental tour. He became a Member of the Institution in 1859, and in 1866 contributed a paper on machinery for the preparing and spinning of cotton (see Proceedings Inst. M. E. 1866 page 199).

William John Macquorn Rankine was born in Edinburgh on 5th July 1820, and received his early education partly at Ayr Academy and the High School of Glasgow, attending subsequently several of the scientific classes in Edinburgh University. In 1839-41 he was a pupil under Sir John Macneill in Ireland, and for several years afterwards was employed on railway and other engineering works in Scotland, chiefly under Messrs. Locke and Errington. In 1851 he established himself professionally in Glasgow, in partnership with Mr. John Thomson, with whom he revived the project of supplying Glasgow with water from Loch Katrine, and surveyed the proposed route. In 1855 he was appointed Regius Professor of Civil Engineering and Mechanics in Glasgow University; and in 1857 was elected the first President of the Institution of Engineers in Scotland, in the formation of which he took a very active part. The valuable results of his original and often abstruse investigations in the various branches of the applied sciences formed the substance of a vast number of papers contributed by him to different learned and professional societies and journals; and he also produced an important series of manuals on engineering subjects, for the use both of students and of engineers. His death took place from heart disease, after a short illness, on 24th December 1872, in the fifty-third year of his age. He became a Member of the Institution in 1872.

Edward Scott was born at Manchester on 19th February 1830, and served his apprenticeship as a draughtsman and engineer with the firm of Messrs. Sharp Brothers, Atlas Works, Manchester, under Mr. Charles F. Beyer. After having been engaged for about two years in the locomotive department of the Eastern Counties Railway at Stratford, he had the management for about four years of the drawing office and erecting shops of Messrs. William Bland and Sons, Union Foundry, Bury, Lancashire, and then went to take charge of the engines and machinery at two collieries in Westphalia. On his father's death in 1859 he returned to Manchester to join his brother in the firm of Messrs. James Scott and Son, engineers and exporters of machinery, in which he took an active part.

Subsequently he commenced business on his own account as an engineer, and after being so engaged for about two years he died on 24th September 1872 in the forty-third year of his age. He became a Member of the Institution in 1865.

The PRESIDENT moved that the Report of the Council be received and adopted, which was passed.

The President said:—Amongst the names of Members deceased, which have been announced in the Report of the Council just read, occurs one of such importance that I cannot proceed to the further business of this Meeting without giving expression to my own appreciation, and I am sure yours also, of the high merit attaching to that name, and of the loss we have sustained: I allude to Professor Rankine. Although a man of science of the highest order, Rankine was professedly and essentially a mechanical engineer. His deep researches into the constitution of matter in its three aggregate conditions of solids, fluids, and gases, are of a strictly mechanical nature, involving as they do the mechanical laws according to which the particles are moved by heat, which is the great potential force in nature, essential alike to the constitution and to the outward motion of matter. The very numerous

published investigations by Prof. Rankine prove, more than words could convey, the breadth, energy, and profundity of his mind; his manuals on engineering science will ever be regarded as standard works, teeming with sound information for the student who is not deterred by the rather formidable array of mathematical expressions, with which they are somewhat overcharged. As a consulting engineer, Rankine's advice was sought on many important questions where exact appreciation of mechanical principles was involved. He leaves no great actual works executed by himself, because his mind was less remarkable for inventive faculty or practical resource than for power of working out the true balance between cause and effect when presented to him in the form of a problem. All who knew Prof. Rankine intimately will bear testimony to his moral rectitude, his genial nature, his kind-heartedness, and the filial affection with which he clung to his aged parents, whom he survived only a few years. His profound knowledge of the mechanical nature of things did not prevent him from appreciating also the poetry of nature; he was a thorough musician, and could compose a humorous song, including the words, and sing it himself in a genial and unaffected manner. Whoever heard him sing his "three-foot rule" or his "railway song" will not easily forget the pleasing effect produced. Having been on terms of intimacy with the deceased, I may be excused for speaking of his personal as well as his scientific merits, the combination of both being necessary in order to produce the truly great man that he undoubtedly was. His death is keenly felt by his friends, by the University in which he, the worthy successor of Prof. Lewis Gordon, had filled the chair of civil engineering for seventeen years, and by the world of science at large. We, the Members of the Institution of Mechanical Engineers, deplore the loss in him of one of our most enlightened and important Members.

The President announced that the Ballot Lists had been duly opened, and the following Officers and Members of Council were found to be elected for the ensuing year:—

PRESIDENT.

Charles William Siemens, . . .	London.

VICE-PRESIDENTS.

I. Lowthian Bell, ...	Newcastle-on-Tyne.
Frederick J. Bramwell, . . .	London.
Charles Cochrane, ...	Dudley.
William Menelaus, ...	Merthyr Tydvil.
John Napier, ...	Glasgow.
John Robinson, ...	Manchester.

COUNCIL.

John Anderson, ...	Woolwich.
Edgar Gilkes, ...	Middlesbrough.
Thomas Greenwood, ...	Leeds.
Thomas Hawksley, ...	London.
Sampson Lloyd, ...	Wednesbury.
Charles P. Stewart, ...	Manchester.
Francis W. Webb, ...	Crewe.

PAST-PRESIDENTS.

Ex-officio permanent Members of Council.

Sir William G. Armstrong, C.B.,	Newcastle-on-Tyne.
Sir William Fairbairn, Bart., . .	Manchester.
James Kennedy, ...	Liverpool.
Robert Napier, ...	Glasgow.
John Penn, ...	London.
John Ramsbottom, ...	Manchester.
Sir Joseph Whitworth, Bart., .	Manchester.

COUNCIL.

Members of Council remaining in office.

Charles Edwards Amos, . . .	London.
Henry Bessemer, ...	London.
William Clay, ...	Birkenhead.
George Harrison, ...	Birkenhead.
John Hick, M.P., ...	Bolton.
Frederick W. Kitson, ...	Leeds.
Walter May, ...	Birmingham.
Percy G. B. Westmacott, . . .	Newcastle-on-Tyne.

The following New Members were also elected :—

MEMBERS.

Charles W. Hawkins, ...	Bombay.
Henry Percy Holt, ...	Leeds.
Henry Hughes, ...	Loughborough.
Edward Westley Jacob, ...	Liverpool.
Edward Jones, ...	Birmingham.
William James Lamb, ...	Wigan.
William Henry Maw, ...	London.
Alfred Muir, ...	Manchester.
Edward Tomkins, ...	Southport.

GRADUATES.

John Sharp Wilbraham Edmunds, . .	Wednesbury.
John Francis Ratcliff, ...	Liverpool.

The President moved the following resolution in accordance with the notice given at the previous meeting :—

"That notwithstanding anything contained in paragraph 1 of "section 5 of the Rules, the next Spring Meeting of the Institution "be held in London, instead of in Birmingham ; and that the Council "be empowered to direct any of the future spring meetings of the "Institution to be also held in London."

Mr. A. Paget proposed, as an amendment, to give the Council the power of directing any of the meetings to be held in any other place than Birmingham, in order to meet a suggestion that had been made that it was desirable to give this power to the Council to enable them to hold other meetings also in London.

Mr. E. Field seconded the proposed amendment.

Mr. R. Williams thought that it would be objectionable to give a general power to the Council to alter all the meetings of the Institution, as it might lead to essentially changing the locality of the Institution.

Mr. E. A. Cowper concurred in this objection, and remarked that at the formation of the Institution the question of its locality was carefully discussed, and it was considered essential for this to be in the centre of the country; the proposed London meeting he looked upon as a desirable experiment, but the seat of the Institution should continue he thought at Birmingham, where it was founded.

Mr. Jeremiah Head thought that with a Council so constitutionally elected as in this Institution, there would be no risk of the power to alter the meetings being objectionably exercised; but it would probably be desirable not to try more than one experiment during the present year.

Mr. L. Olrick suggested that if the trial of a London meeting in the spring proved so successful as to make it desirable to have another meeting there in the year, the Council would be enabled by the proposed amendment to carry this out.

Mr. W. W. Hulse would support the original resolution, if it was to be looked upon as a trial of a London meeting with the object of seeing whether it would be desirable to consider a removal of the Institution to London.

The President remarked that it would be better that such a serious question as a change of locality of the Institution should be submitted as a direct question at some other time, and not be raised indirectly in connection with the present question, which was simply the expediency of making a trial of a London meeting.

Mr. A. Paget said he had no intention of raising the question of moving to London immediately, but his intention and that of the seconder of the amendment was simply to give the Council power to hold other meetings in London this year, as they could not otherwise obtain power to hold more meetings in London until the next anniversary meeting. If however the amendment was to be understood as implying a wish to move the Institution to London before the experiment of holding meetings there had been fairly tried, he preferred to withdraw it.

The original resolution was then passed unanimously.

The PRESIDENT then said the other resolution of which notice had been given at the previous meeting was:—"That the Council be empowered to ask by circular addressed to all the Members, the opinion of each Member as to whether a suitable house should be built for the seat of business of the Institution, and if so in what locality that house should be built." If this resolution should be adopted by the meeting, it was proposed to issue a circular giving a copy of the resolution and asking the opinion of each Member upon the subject; and if the first of these two questions were not answered in the affirmative, the second question would fall to the ground.

Mr. J. KERSHAW suggested that it would be preferable for the first question, referring to the desirability of building a house, to be asked separately, and the answers obtained, before the second question as to the locality was asked; the two questions could he thought be better answered separately, and if the first should be settled in the negative there would not then be any occasion to put the second.

Mr. A. PAGET supported this suggestion, and thought it would be objectionable to put the two questions together, because any one answering the first in the negative would not be in a position to express an opinion upon the second.

Mr. J. B. ALLIOTT enquired whether a member answering the first question in the negative and not answering the second would be disqualified from giving an opinion afterwards on the second question.

Mr. JEREMIAH HEAD proposed that in order to prevent any difficulty the second question should be put in the form,—if it be decided for a house to be built, then where should it be.

Mr. W. W. HULSE thought the first question should be put separately, in order to ascertain first whether it was the wish of the members to expend the funds of the Institution on the erection of a house; and there would be an advantage in the second question being deferred until after the London meeting.

Mr. E. H. CARBUTT thought the whole question had better be deferred until after the London meeting had been tried.

Mr. J. J. Bagshawe thought it would be preferable to defer the whole matter until the next anniversary meeting, which would give an opportunity for the members to consider more fully the questions of the cost of building and the funds available for the purpose.

Mr. C. C. Walker concurred in the desirability of deferring the matter for the present; the question of the locality of the house involved the large question of the permanent position of the Institution, which was of such importance that it should be brought before the members in a manner to allow ample time for careful consideration.

Mr. D. Adamson thought the Institution should certainly have a house and meeting room of their own, not to be dependent upon obtaining accommodation elsewhere; it appeared to him desirable for some particulars to be supplied about the financial position of the Institution and the funds available for building, as a guide to the members in forming an opinion on the subject.

Mr. W. May, as a member of the Finance Committee, remarked, in reference to the request for information respecting the funds of the Institution, that a complete statement of the finances was furnished to the Members each year in the published annual report of the Council read to the anniversary meeting. He thought the Institution should have a house of their own, but the whole matter should be proceeded with cautiously; and he did not see any objection to its postponement for the present.

Mr. A. Paget proposed that, as there appeared so much diversity of opinion on the subject, and there could not be any real loss if the question were adjourned, the whole should be postponed for the present, so as to allow time for further consideration of the subject; he should have a difficulty in answering the questions until he knew the amount of success of the meetings in London.

Mr. E. A. Cowper said he believed there was not any strong feeling entertained in favour of building, and the subject might be safely left for further consideration; and it might be found ultimately that there was not any necessity for erecting a building, at any rate there was no occasion for any hurry.

Mr. J. Ramsbottom remarked that there was no desire on the part of the Council to enter hastily upon building, and the proposed resolution did not imply incurring any expenditure at present, but only provided the means of ascertaining the opinions of the Members. There could not be any objection to deferring the question until after the London meeting, but a caution was required against drawing any positive conclusion from the result of a single meeting in London. In reference to the mode of putting the questions for obtaining the opinions of the Members, he did not see how any opinion could be given satisfactorily unless both questions were put together, as the answer to one might depend materially upon the answer which might be given to the other.

Mr. L. Olrick suggested for the consideration of the Council that some of the surplus funds should be applied to giving premiums for the best papers read during the meetings of each year.

Mr. T. W. Plum asked what majority of opinions would be considered by the Council sufficient for acting upon.

The President said it was the desire of the Council to obtain a full expression of the opinion of all the Members for their guidance and careful consideration in preparing the proposals to be afterwards submitted to the Members; but not to pledge themselves to any particular course of action, and certainly not to take any decisive action if there should be only a small majority in favour of any particular course. The object was to obtain full information about the opinion of the Members on the subject honestly and fairly, and he considered that if the second question were not put in connection with the first there would not be an opportunity for fully expressing their opinion, as some might be in favour of building a house if it were to be in a certain locality only, and opposed to building if in any other locality.

The present question was simply that of giving the Council power to obtain the opinions of the Members by circular, and he suggested that it would be advantageous and would save time on future occasions if the resolution were made general, so as to apply to any cases that might arise. He proposed therefore to withdraw the

original resolution, and substitute one in general terms, but with the intention of not acting upon it until after the trial of a London meeting had been made.

The amendments having been also withdrawn, the following resolution was then passed unanimously:—

"That the Council be empowered to ask at any time, by circular "addressed to all the Members, the opinion of each Member upon "any question respecting the Institution."

The President then remarked that, by the present Rules, no alterations in the Rules or Byelaws could be made except at an Anniversary Meeting, but there was not any provision for previous notice to be given of such alterations, although it had been the practice for notice to be given at a previous meeting; and the Council thought it desirable for such notice to be provided for by the Rules, in order to ensure due consideration of any alterations. He therefore proposed the following resolution on the subject, and it was passed unanimously:—

"That no alteration in the Rules or Byelaws be made at any "Anniversary Meeting unless notice of such alteration has been "given at the previous General Meeting; a copy of this notice to be "sent to each Member with the circulars for the Anniversary "Meeting."

The following paper was then read:—

DESCRIPTION OF AN IMPROVED APPARATUS FOR WORKING AND INTERLOCKING RAILWAY SIGNALS AND POINTS.

By Mr. WILLIAM BAINES, of Smethwick.

At railway junctions and stations some plan of Locking the Points and Signals by a self-acting apparatus is generally employed, so that when any one line is opened for a train to pass through, all other lines which could interfere with it are blocked, in order to prevent any risk either of trains coming into collision, or of a train being accidentally turned upon a wrong line. This arrangement has been in use for a long time past, and is becoming generally adopted for the purpose of ensuring greater safety, and it is now required by the government regulations for all new work. In the cases where a train on one line would be interfered with by any traffic on a second or third line, the object is that the safety of the train shall not depend simply upon the signalman having remembered to block the second and third lines before opening the first line for the train to pass through, but that the opening of the first line shall not be capable of being effected until after the others have been blocked, and the act of opening it shall lock both the points and signals of the other lines, so that they cannot be accidentally shifted as long as the first line remains open.

An illustration of the points and signals for an ordinary junction is shown in the plan, Fig. 1, Plate 1. In this case it will be seen that the up branch train requires both the up and down main lines to be blocked, and consequently the lever which lowers the signal for the up branch train to pass through has to lock the levers for the up main-line signal and the down main-line signal, keeping

these signals up to block both the main lines; and it has also to close the trailing points for the up branch train to pass on to the main line. At the same time the facing points for the down branch are locked open, so that in the event of any train moving on the down main line at that time, it will be turned into the branch, avoiding the train which is entering the up main line from the up branch.

The connection between the several levers has therefore to be arranged so that they can only be shifted in a certain order, and that the signal cannot be lowered for the up branch train to pass through on to the main line until all the previous movements required have been effected. This is illustrated by Figs. 3 and 4, Plates 2 and 3, showing a front elevation and transverse section of the ordinary set of nine levers used for such a junction. The levers for moving the several points and signals are grouped together side by side, Fig. 3, for convenience of working a number of them from one signalbox, and for carrying out the arrangements for making them mutually lock one another as required. The levers A A work in quadrant guides B, and each has a spring detent C, Fig. 4, to hold it in either extreme position by dropping into a notch at either end of the quadrant guide; this detent is released by the hand in grasping the handle of the lever.

Nos. 1 and 2 move the Down Main-line Distant and Station Signals.
Nos. 8 „ 9 „ Up „ „ „ „
Nos. 3 to 7 belong to the Branch line.
No. 3 moves the Facing Points leading out of the down main line.
No. 4 „ corresponding Signal.
No. 5 „ Trailing Points leading into the up main line.
No. 6 „ corresponding Signal.
No. 7 „ Distant Signal on the Branch line.

The levers Nos. 1, 2, 3, and 8, are each free to be moved over and back singly; the rest, Nos. 4, 5, 6, 7, and 9, are all locked in their ordinary state.

But when 3 is pulled over, 4 and 5 are unlocked and can be pulled over.
„ 5 „ 6 is unlocked „ „ „
„ 6 „ 7 „ „ „ „

As long as No. 7 lever remains over, Nos. 6, 5, 4, and 3 continue

locked in their new position, and they can only be released by bringing each back in the reversed order of the former movement.

When 7 is brought back, 6 is unlocked and can be brought back.
" 6 " 5 and 4 " " "
" 4 " 3 " " "

No. 7 lever moves the branch distant signal, which ordinarily stands up, blocking the line; and this interlocking prevents that signal from being lowered to allow an up branch train to pass through on to the main line until after all the requisite arrangements have been completed in the station by the other three levers; and then these three levers cannot be shifted again until No. 7 lever is brought back, thus putting up the distant signal again to block the branch.

The details of the interlocking of the whole of the levers need not be described, and it will be sufficient to mention that Nos. 2 and 3 are mutually interlocking; they can either of them be put over and back singly, but when No. 2 is put over, No. 3 is locked and cannot be shifted until No. 2 is brought back; also when No. 3 is put over, No. 2 is locked. These are the levers for the down main-line station signal and the facing points, so that the signal cannot be lowered for a down main-line train to pass, if the facing points are opened to the branch; and the act of lowering the main-line signal locks the facing points closed, all right for the main line. The arrangement of interlocking the rest of the levers is such that a down and an up branch train can both pass the junction at the same time, as they do not interfere with each other any more than a down and an up main-line train; or a down branch train and an up main-line train can pass simultaneously; but an up branch train cannot pass the junction unless both the up and down main lines have been blocked, as both those lines are interfered with by this train.

For effecting this interlocking, several ingenious plans are in use, acting on the general principle of preventing the motion of the levers that have to be locked, by means of different arrangements of catches, which are thrown in or out of gear by the lever of the particular point or signal that is being used, so that as long as this

lever is in action, all the others are locked by the catches and prevented from being moved. Each of the levers is usually locked, either by a trigger which catches the lever in a notch, and is pulled aside by a connecting rod from the other lever; or by a stud on the lever, which is caught by a cam fixed upon a rocking shaft that is partially rotated by the movement of the other lever. In all these modes of locking the levers, the locking catches have to resist the whole strain upon the levers when any attempt is made to pull them over while locked; this is a severe strain, being multiplied two to four times by the leverage of the handle over the part where the locking catch acts upon the lever. The result is a certain extent of play, owing to the springing and to the effect of wear of the locking parts in the catch and lever; so that the points and signals cannot be held rigidly shut whilst locked, but are able to be left partially open; and any such liability destroys the absolute security which is desired to be effected by the interlocking.

The Locking arrangement shown in Plates 2 to 7 and designed by the writer acts upon the different principle of locking the detents that secure the levers, instead of locking the levers themselves. This principle of locking, which has been attempted before but not in a practically successful manner, has two important advantages: the levers cannot begin to move so long as the detents are locked, and there is consequently no risk of the points or signals standing partially opened; also the locking apparatus is not subjected to any strain from an attempt to pull a lever over when locked, and the only force that can be applied to the locking gear is the pressure of the fingers upon the handle of the detent. The small pressure upon the wearing parts also renders their wear very slight; and there is the advantage of reduction in friction, and consequent reduction in the power required for working the levers. This arrangement provides the means for locking the levers either in the forward or in the backward position with equal facility; and an important practical advantage is the simplicity of construction and readiness of access to all the parts, any of which can be easily taken out and quickly replaced.

In Figs. 3 and 4, Plates 2 and 3, is shown the application of this interlocking apparatus to a set of nine levers, and the details of the locking gear are shown in the different positions of the levers given in Figs. 5 to 12. The detent C of each lever A is connected to a locking bar D by a short cross lever E, Fig. 4, so that the locking bar is pushed down by the act of raising the detent out of the notch in the quadrant guide B that holds the lever at either extremity of its motion. Above the main shaft F on which all the levers are centred, a second smaller shaft G is fixed, which passes through a quadrant arc in the foot of each lever A, as seen in Figs. 5 to 12, allowing the required range of motion of the levers. On this upper shaft G are slipped loosely a number of short tubes or rockers J J, one of which is shown half full size in Figs. 19 and 20, Plate 7; these have cams upon them, which act upon projecting tappets H fixed one upon the bottom of each of the locking bars D of the levers A, and when a cam is held up under one of these tappets, it prevents the locking bar from being pushed down, and consequently the detent of that lever cannot be raised out of the notch in the quadrant, and the lever is thereby locked and prevented from being moved until the cam is removed that holds up the bottom of the locking bar. The rockers that carry the cams are most of them only the length of the space between two contiguous levers, and have a cam at each end, one projecting forwards and the other backwards, as shown in Figs. 19 and 20, so that when the locking bar of one of the two levers is pushed down, as in Fig. 6, the cam under the locking bar of the other lever is raised, as in Fig. 5, and prevents the locking bar of that lever from being lowered. This is the case between Nos. 2 and 3 levers in Fig. 3; when No. 2 lever is put over, the act of raising the detent to release the lever places a stop under the locking bar of No. 3 lever, so that the detent of the latter cannot be released until No. 2 lever is brought back again. The same cams acting in the opposite direction serve also to lock No. 2 lever when No. 3 is put over.

When the cam on a rocker is pressed down by the tappet of the locking bar, it is held down during the movement of the lever by the curved slot in the foot of the lever A engaging with a

stud I which projects from the side of the cam, as shown in Figs. 19 and 20, Plate 7. There is a notch at one end of the slot in the lever, as shown in Figs. 5 to 12, which allows the stud I to rise when the lever is in its ordinary position, as in Figs. 5, 7, and 8; but the stud becomes engaged in the slot as soon as the lever has commenced moving, as in Figs. 9 to 12. This arrangement ensures the second lever being effectually locked before the first lever has done more than just begin its movement; and the second lever cannot be unlocked again until the first is brought back completely home. The practical result is that before the lever has moved $\frac{1}{8}$ inch in the quadrant the locking of the second lever is effected. As the extreme strain to which the locking gear is subjected is limited to the pressure of the fingers upon the detent trigger in grasping the lever handle, all the parts can be made a good fit, and keep in that condition without appreciable wear for a long period of working.

The small strain to which this locking gear is subjected, and the consequent small wear and tear, are important practical advantages for securing safety, as all risk is obviated of any lever being partly moved before the locking of the other connected levers is completed; such a risk is liable to occur when, as in the ordinary arrangement, the locking gear is applied to lock the levers themselves, and is consequently exposed to the full strain of a man pulling with a leverage of about 3 to 1. In that case the play arising from the greater wear and the springing of the parts is liable to allow a signal which should be kept fully up to be so far lowered, or a point which should be kept quite closed to be so far opened, as to cause risk of accident.

An illustration is given in the plan Fig. 2, Plate 1, of the points and signals at an unusually complicated junction, where very extensive and intricate locking arrangements are required. This junction is on the Furness Railway at Lindal Cote, and the working has been successfully effected by the locking apparatus already described, extended in application in the manner shown in Figs. 13 to 17, Plates 5 to 7. This junction is unusually complicated,

because it has a cross-over road connected by points with both the up and the down main line, and with two branch lines M and N on the up side, and three branch lines P, Q, and R on the down side. The most complicated part, as regards the interlocking arrangements for the points and signals, is the catch points S on the up side, which are required to be kept closed for the cross-over road and open for the catch siding T, in order to prevent any risk of the main line being fouled by traffic on the branch lines M and N; and the catch points S can only be opened for the cross-over road after the signals are set to block both the main lines and the branch lines on the opposite side. There are in consequence as many as nine points and seven signals all connected with these catch points S and mutually interlocking.

There are eighteen levers at this junction, as shown in the front elevation, Fig. 13, Plate 5; and the extension of the apparatus for effecting the very complicated interlocking arrangements that are required in this case is made by simply increasing the number of rocker shafts G from one to four, two of these being placed above the main shaft F, and two below it. The details of the locking gear are shown in the different positions of the levers represented in Figs. 14 to 17, Plates 6 and 7; and in Fig. 18 is shown another pattern of casting for the foot of the levers, in which the arm to work the points or signal can be attached either at the front or at the back, as shown dotted at K K.

The same construction of locking apparatus admits readily of further extension to any number of rocker shafts that may be desired; and it is found to work with complete success and freedom from derangement, without involving any trouble in keeping it in order. The pressure upon the working parts being very small, they do not require oiling; and in case of any one of the rockers having to be removed at any time, this can be effected very readily and quickly, as they are carried loosely upon the rocker shaft, which can be withdrawn to release any one of them without interfering with the rest, a duplicate rocker shaft being at the same time slipped into the place of the shaft that is being withdrawn.

The working of signals at a distance is seriously interfered with by the changes of length in the connecting wire, which arise from the expansion and contraction caused by changes of temperature; and an adjustment of the length has consequently to be made from time to time. This is usually done by a right-and-left-hand screw, but the adjustment is necessarily imperfect in effect, because changes of temperature are liable to take place too suddenly to admit of being met by this means; and in all cases where the signal is out of sight the adjustment is uncertain, the amount required being only ascertained from the relative tightness or slackness of the wire; also considerable delay is liable to occur before the adjustment is effected. An expansion of as much as 6 inches in a length of 600 feet has been observed to take place within half an hour from the effect of the sun suddenly breaking out in cold weather; and a total change of length of 15 inches in a distant-signal wire of 1000 yards length is found to take place between the extremes of temperature in this country. The evil arising from this expansion or contraction is that the signals are liable not to be pulled down fully to their intended position, and thus cause interference with the traffic and safety of the line; and there is also the danger of the signal wire being broken by extreme tension in frost.

The only efficient way of removing this difficulty is by having a self-acting compensating apparatus which shall always adjust itself to any change of length from expansion or contraction, so that at all times the position of the signal shall correspond exactly to the position of the lever, and the wire have always the same tension upon it. Several plans have been tried for effecting this object, but practically the means of adjustment in use is generally limited to a right-and-left-hand screw in the signal wire, or some similar hand adjustment, thus depending upon the attention of the signalman. In the former practice of working signals independently of one another, without any mutual interlocking, a partial self-adjustment was obtained by working the signal by means of a weighted lever, which was thrown over from one side to the other, and kept the wire in tension by its weight; but this plan had to be abandoned on the adoption of the interlocking principle.

In Plate 8 is shown a self-acting Compensating apparatus designed by the writer, which is of simple construction, and has been found thoroughly satisfactory in operation; Fig. 21 is a plan and Fig. 22 a side elevation showing it as applied to distant signals. It consists of a horizontal rocking shaft A about 6 feet long, having an arm B fixed upon it at one end, which is connected by a vertical rod to the signal hand-lever; and at the other end the shaft carries a pulley C, round which is fixed the chain attached to the wire D working the signal. The rocking shaft A has a horizontal radial movement, being carried in a bearing at the lever end which is pivoted in line with the signal-lever connecting-rod; and a roller E on the pulley end traverses a curved bearing rail F of about 2 feet length, this end of the shaft being connected to a heavy suspended weight G, which acts constantly to keep the signal wire D in uniform tension. The action of the signal lever is not in any way interfered with, being just the same as if both ends of the shaft A worked in stationary bearings; but the shifting of the radial rocking shaft between the two dotted positions shown in the plan, Fig. 21, allows the extreme change of length from change of temperature to take place in the signal wire without any change in the tension of the wire; so that the action of the signal can always be relied on to be just the same as if no expansion or contraction had taken place in the wire. This is a point of great importance where the signal is out of sight of the signalman, as in the case of a tunnel or a curved cutting, since the only means by which the signalman can then judge of the correct action of the signal is by a repeater worked in the signalbox by the lower return wire H from the signal; but the indication of this repeater can only be given correctly when self-acting compensating apparatus is employed, as its indication is rendered false by any uncompensated change of length in the wire.

In the case of signals working at a short distance and with a single wire, the lighter weight which is sufficient for maintaining the required tension of the wire is not sufficient to resist the pull of the signal lever; and a catch I working in a fixed rack K is then added, as shown in Figs. 23 to 25,

Plate 9, for the purpose of preventing the weight G being drawn up and the rocking shaft A shifted, when the signal lever is moved. The catch I, which holds the shaft A and pulley C stationary while the signal lever is in action, is ordinarily kept up clear of the rack K by its weighted end; but whenever the rocking shaft is rotated by the signal lever, the catch is pressed down into the rack by means of a cam L on the end of the shaft, which holds the catch in the rack in whatever position the shaft A may happen to be at the time. The sliding bar M supporting the free end of the rocking shaft is carried between rollers, so as to move with very little friction, and it works freely without requiring oiling; the first of these that were put to work were made a close fit in the guides and without rollers, and were found liable to work stiffly from exposure to the weather, unless attended to and oiled; but this objection is entirely avoided in the subsequent ones with the rollers.

This compensating apparatus has been at work in several places for a year and a half, and has proved completely satisfactory, effecting the intended object under all circumstances and without requiring any attention in working.

Mr. Baines exhibited a working model of a set of nine levers, employed for working the seven signals and two points at an ordinary junction, illustrating the manner in which the several levers were made mutually interlocking, and showing that the moment the detent of any one of the levers was lifted, the locking of all the connected levers was complete, and they continued securely locked until the detent of the lever first moved was pushed home again in its notch. He also showed by the model the action of the compensating apparatus in maintaining the correct position of the signal, whatever alterations might take place in the length

of the connecting wire from changes of temperature. He remarked that the necessity for employing some self-acting compensating arrangement was shown by the fact that in this country the ordinary signal wires working without such a provision were frequently found to be broken in frosty weather, while in the heat of summer they became too slack to move the signals to the full extent, thus involving risk of interference with the traffic. The extreme variation liable to occur in the length of the wires for distant signals was about 15 inches in this country; but in the more severe climate of Russia it was found to amount to as much as 3 feet.

Mr. J. Ramsbottom enquired whether in the rack and paul of the compensating apparatus there was not a risk of the paul catching on the points of the teeth, instead of entering the notches of the rack, which would interfere with the rotation of the shaft for working the signal wire.

Mr. Baines replied that there was not found to be any difficulty of that kind in the actual working of the compensating apparatus, as the paul did not drop by its weight into the notches of the rack, but was pressed down by the cam on the shaft working the signal wire; and even if the paul happened to catch at first on the point of a tooth, the pull upon the wire would immediately drag it forwards into the notch.

Mr. F. W. Webb thought the arrangement of the rack and paul in the compensating apparatus was very good, and he enquired whether a rack had been in use before for the purpose.

Mr. Baines replied that a rack and paul had long been used for adjusting by hand the length of signal wires, but not arranged to be self-acting; but in the plan now shown the special advantage was the radial movement of the shaft.

Mr. E. A. Cowper remarked that the first part of the paper, relating to the very great advantages that resulted from interlocking signals and points, on the principle now long since adopted by Messrs. Saxby and Farmer, certainly showed the value of that arrangement, and he thought their names should have been mentioned. The use of rock shafts to effect the locking was not

new, but there might be some difference in the way they were here used. The self-acting compensating apparatus for correcting the variations of length in the signal wires appeared to him a very ingenious and novel arrangement for the purpose.

Mr. Baines said the principle of locking the detents instead of the levers was not new, but the mode of carrying it out in the other plans of signal apparatus was impracticable in consequence of the friction, which could not be overcome by the grip of the hand; in all other respects the arrangement now described was essentially different, and he enquired what point was considered similar to Messrs. Saxby's arrangement. In his own apparatus there was a special advantage for facility of repairs, as the rockers were all slipped loosely upon the horizontal shafts, and any of them could be readily removed and quickly replaced whenever required, and the friction was reduced to a minimum.

Mr. R. H. Tweddell enquired how the safe working of so complicated a set of levers as those shown was ensured in the event of a change of signalman being required.

Mr. E. A. Cowper replied that there was no difficulty in this respect even in the most complicated cases, with properly arranged interlocking apparatus, as the man had a plan of the line before him in the signal box, showing the several points and signals all numbered, and the levers were numbered to correspond; the great advantage of the interlocking system was that it was impossible for the levers ever to be moved in such an order as to cause risk of an accident, the right lever or levers alone being unlocked at any moment, while the others remained locked.

The President enquired what length of time the locking apparatus described in the paper had now been at work in any instance, and what were the results of working.

Mr. Baines replied that the apparatus with eighteen levers at Lindal Cote Junction had been nearly a year in constant work, and continued in complete working order without having required any attention or oiling, in consequence of there being so little friction and strain in the moving parts of the locking apparatus, and so little work to be done by the detent handles in locking and unlocking.

Mr. E. A. Cowper noticed that the model exhibited of the locking apparatus showed a rocking bar projecting above one of the rails, which would be depressed by the wheels of a train passing over it; and he enquired whether the action of this contrivance was also to lock the point lever.

Mr. Baines replied that the object was to prevent any risk of the points being shifted by the signalman or by any accidental cause whilst a train was passing over them, many accidents having arisen from such an occurrence causing part of a train to be turned on to a different line. A short rocking bar was placed alongside one of the rails, standing up a little above the rail level, and was pivoted at each end at its outer edge, so that it could be depressed level with the rail by the wheels of a train passing over. This bar was connected by a lever to a coiled spring under the signal apparatus, so as to wind up the spring each time that a wheel passed over the bar; this brought a stop under the detent rod of the point lever, so as to keep the detent locked until the spring had completely uncoiled, and consequently the points could not be shifted until after the last wheel of the train had passed, and after a further fixed interval of time. This self-acting locking of the points by the passage of a train was independent of the interlocking with other points or signals, and was provided as an additional security against risk of accident.

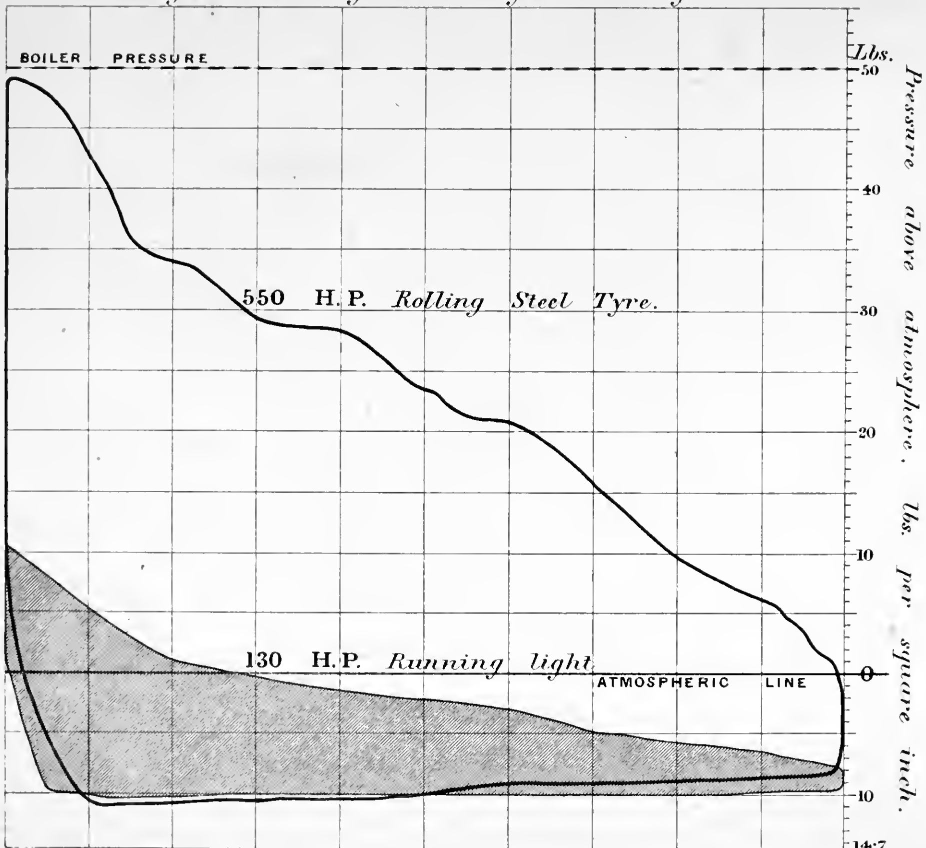
The President remarked that the apparatus described in the paper, although similar in general principle to other arrangements for the same purpose, appeared to him to comprise several ingenious contrivances for improving the mode of interlocking railway signals and points; he was particularly struck with the ingenious and novel compensating arrangement, for adjusting the length of the signal wires by self-acting means, so as to ensure always the correct action of the signal. Any improvement in the mode of signalling on railways was of the greatest importance, involving as it did the safety both of life and of property.

He proposed a vote of thanks to Mr. Baines for his paper, which was passed.

The Meeting then terminated. In the evening a number of the members dined together in celebration of the Twenty-sixth Anniversary of the Institution.

ALLEN GOVERNOR.

Fig. 1. *Indicator Diagrams from Engine driving Steel Tyre Rolling Mill.*



Diagrams illustrating action of Governor.

Fig. 2.

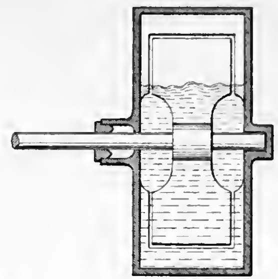
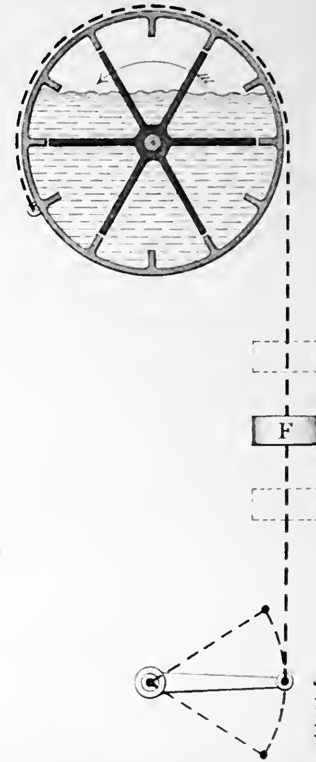


Fig. 3.



(Proceedings Inst. M. E. 1873.)

ALLEN GOVERNOR.

Fig. 4. Side Elevation.

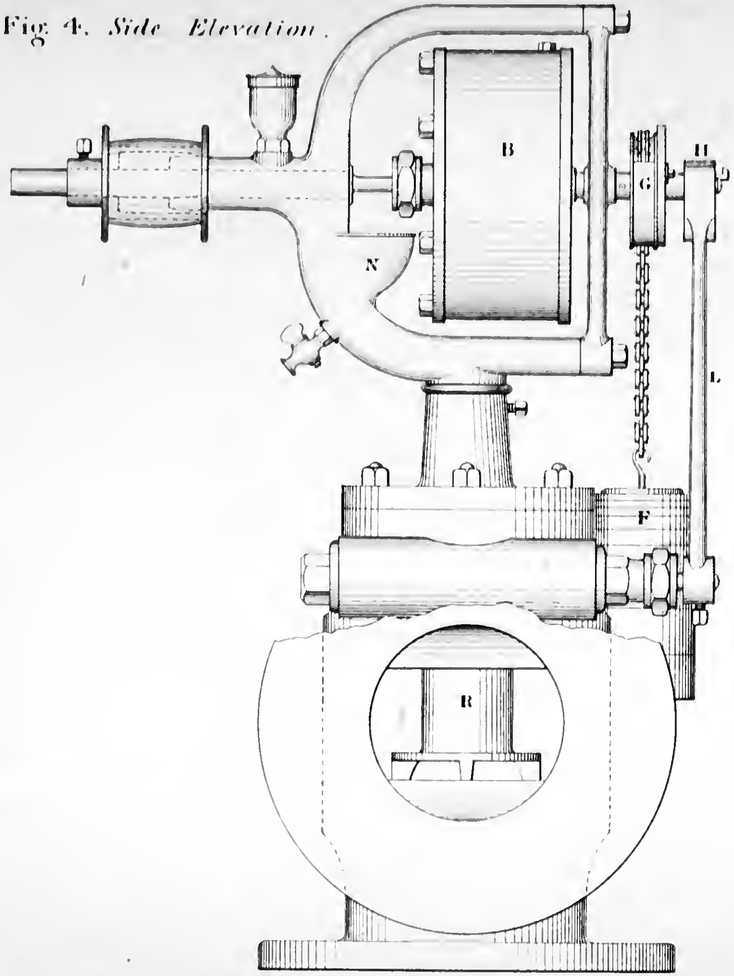
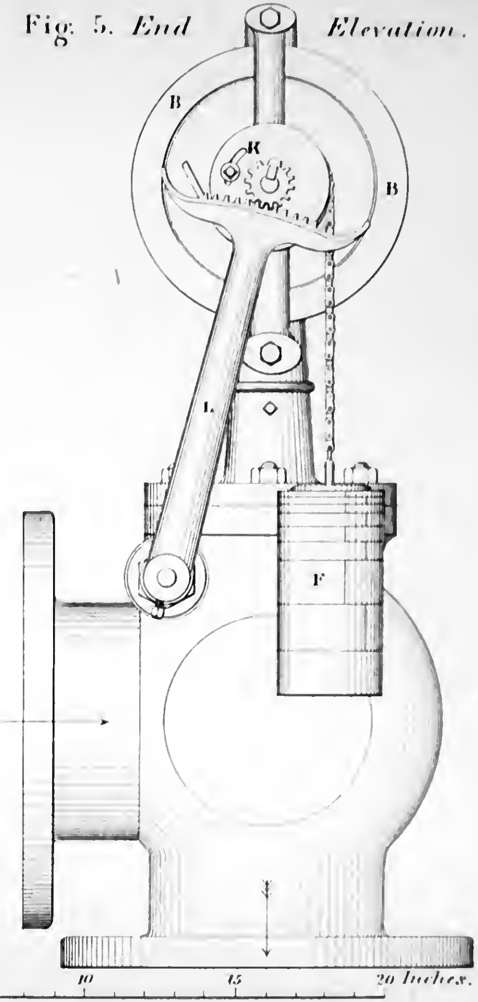


Fig. 5. End Elevation.



(Proceedings Inst. M. E. 1873.)

Scale 1/8th

Plate 11.

ALLEN GOVERNOR.

Fig. 7. *Transverse Section.*

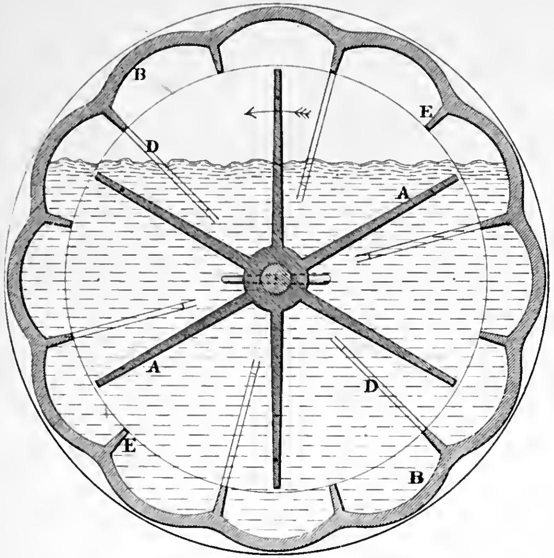
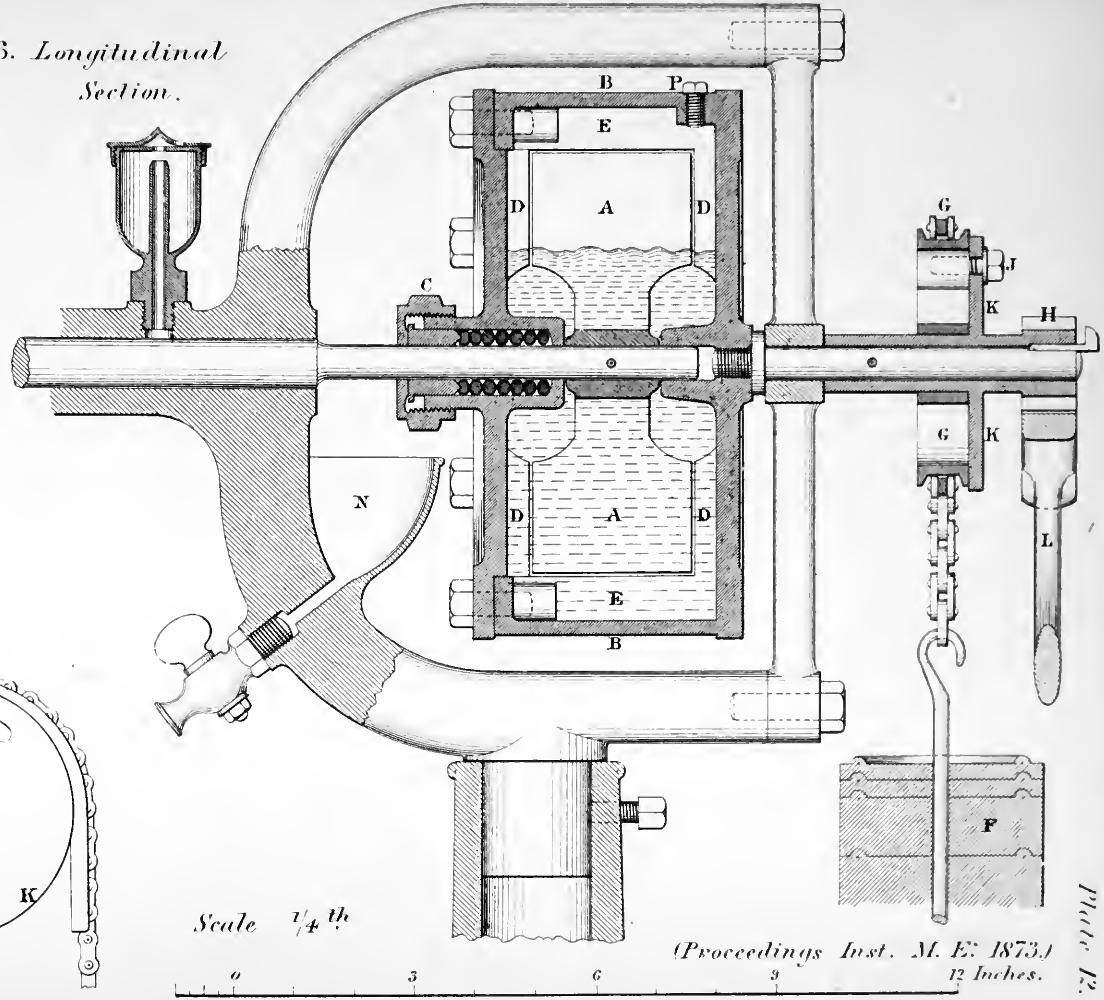


Fig. 6. *Longitudinal Section.*



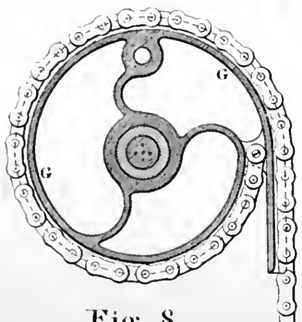


Fig. 8.

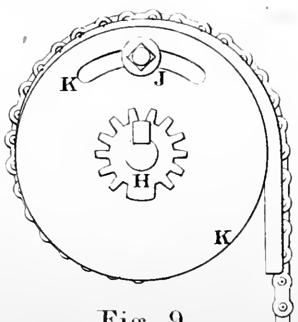


Fig. 9.

(Proceedings Inst. M. E. 1873.)

Plate 12.

ALLEN GOVERNOR.

Fig. 14. *Sectional Plan of Throttle Valve.*

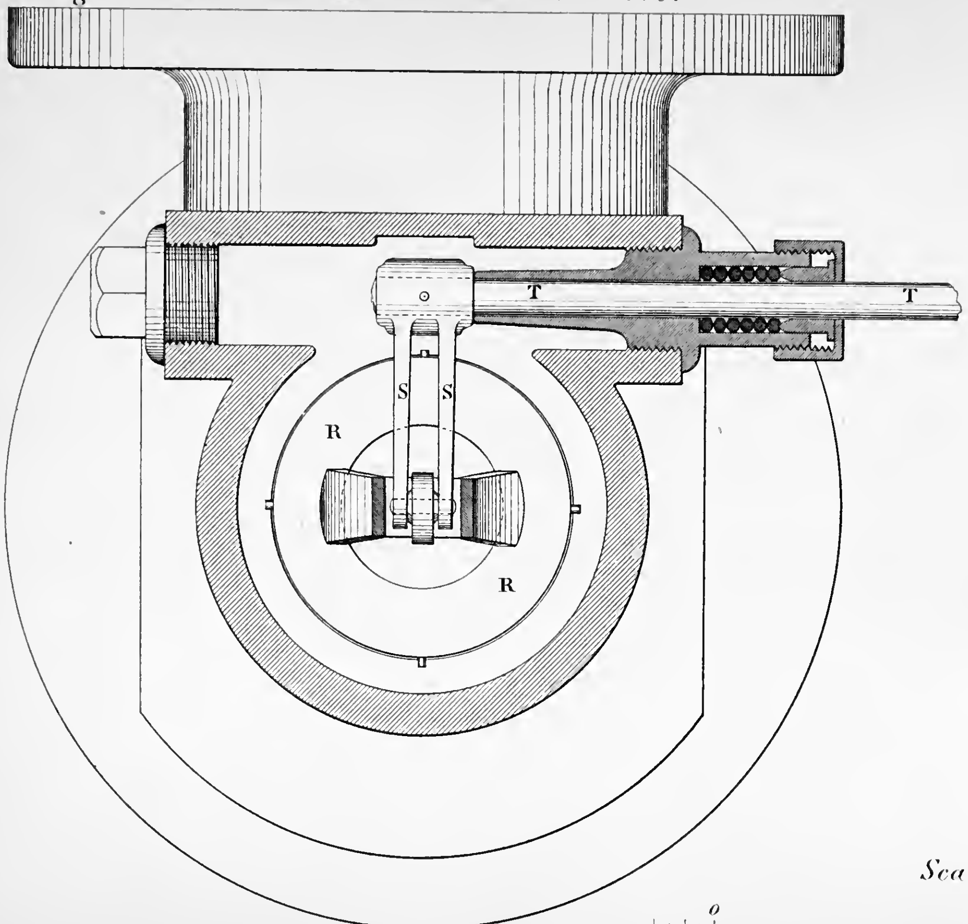


Fig. 10.

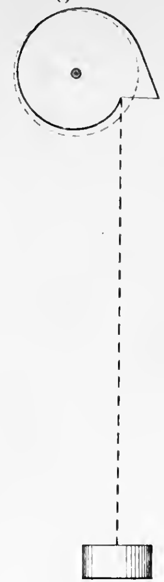


Fig. 11.

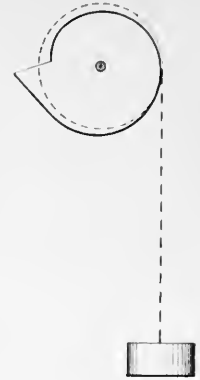


Fig. 12.

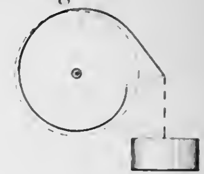
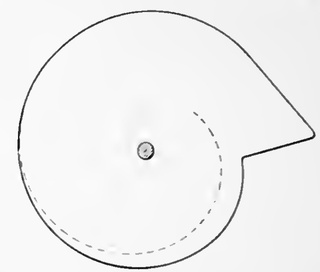


Fig. 13. *Scale 1/4th*



Scale 1/4th

ALLEN GOVERNOR.

Throttle Valve.

Vertical Sections.

Fig. 15.

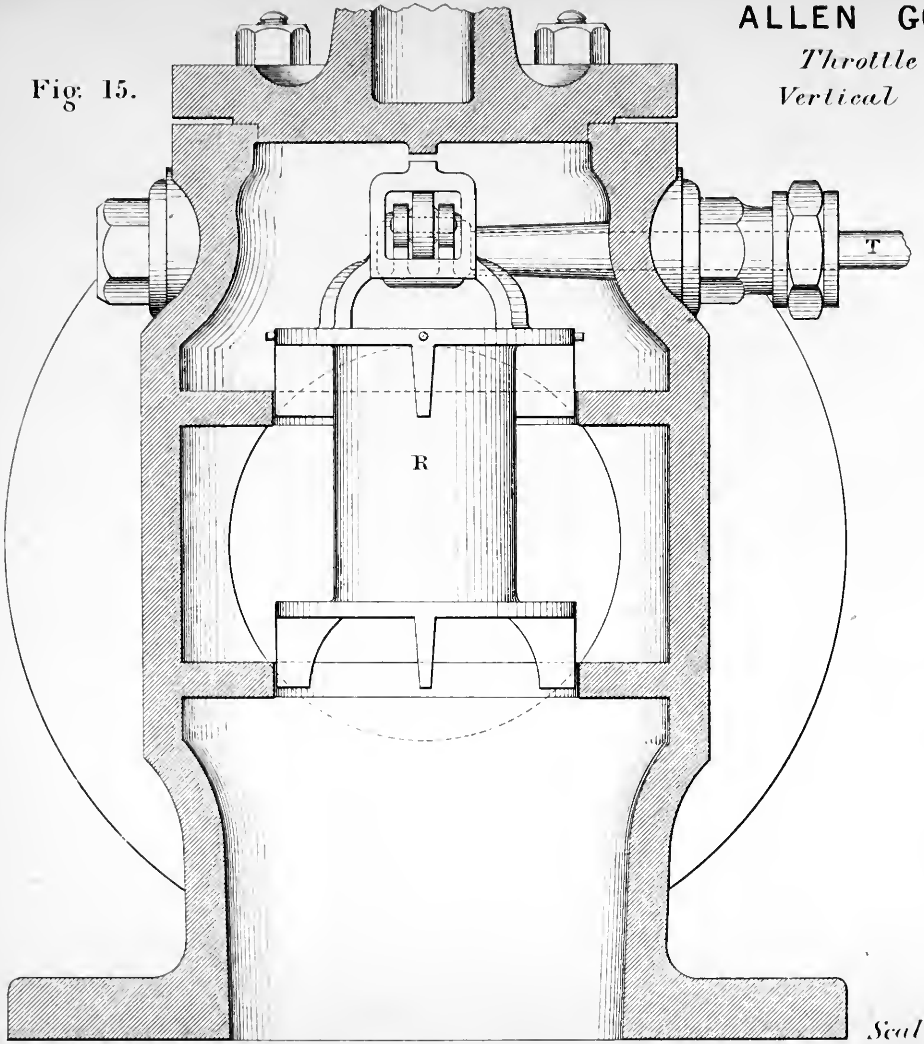
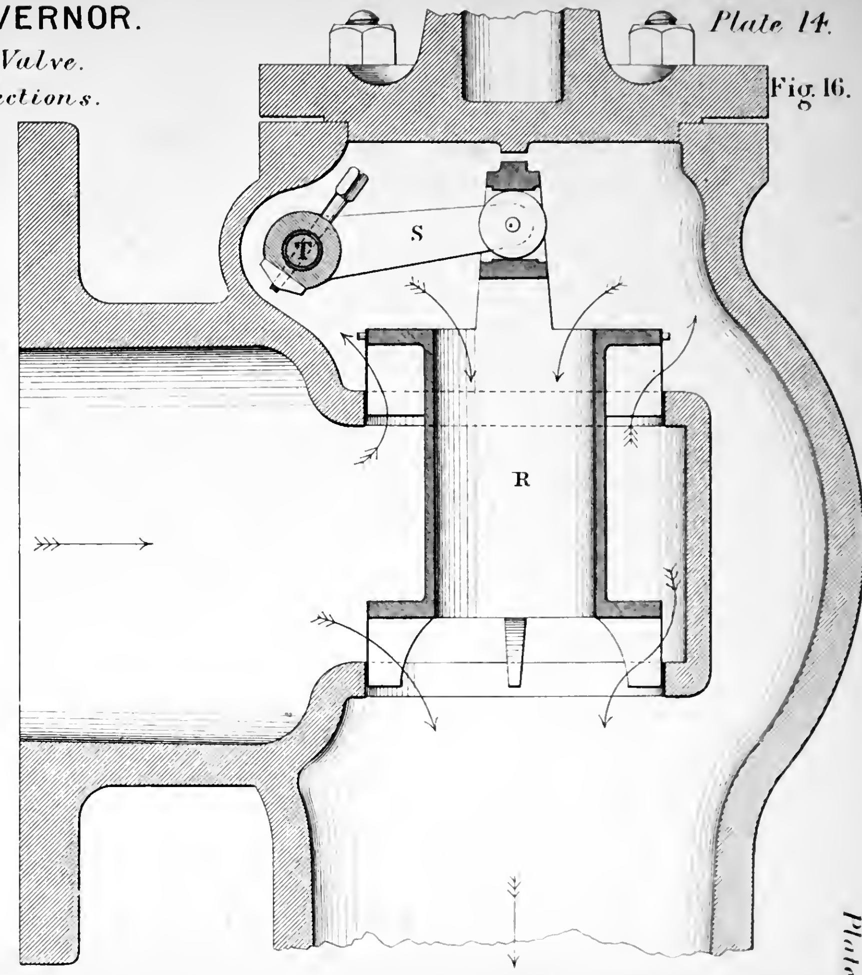


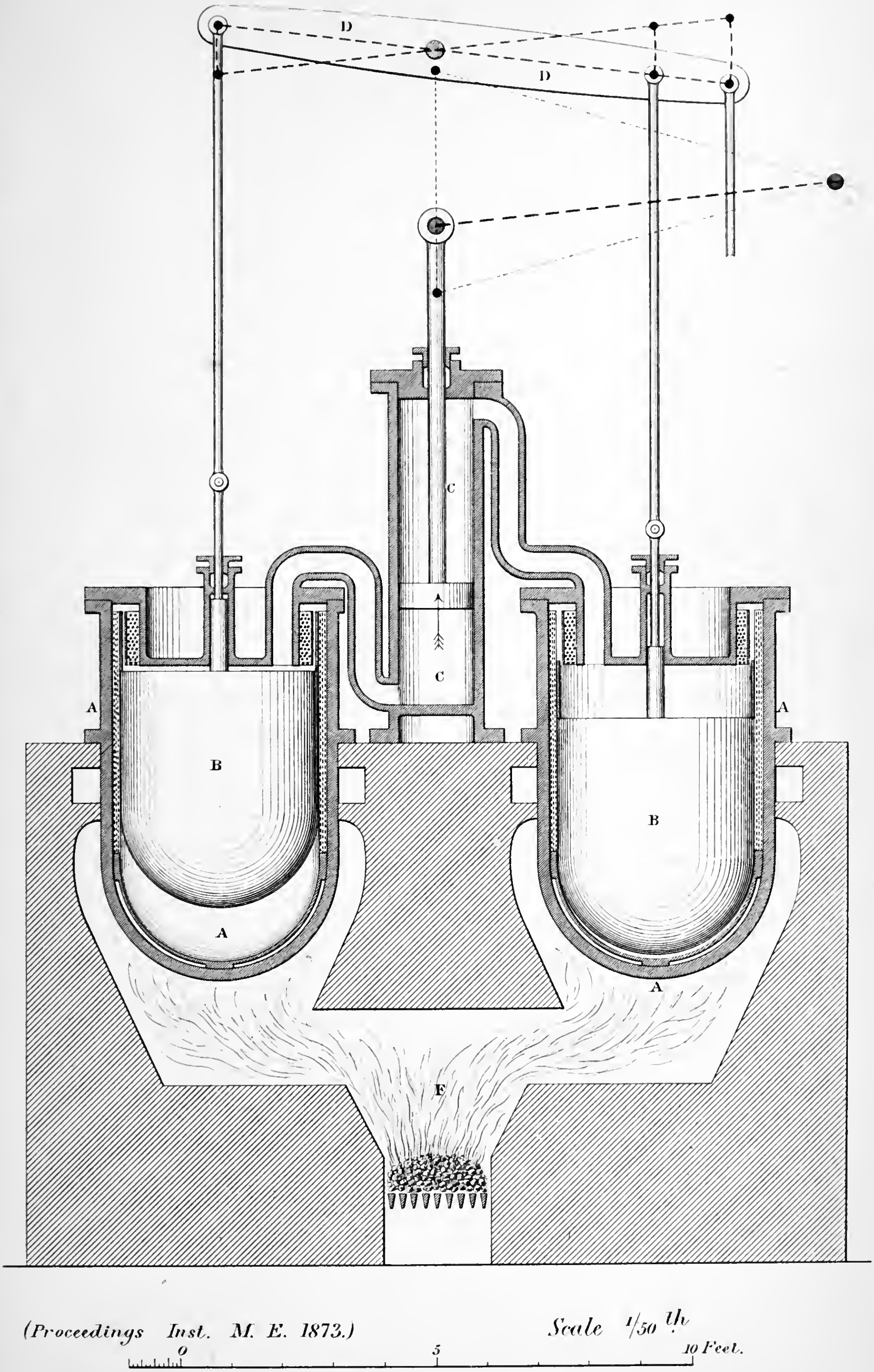
Fig. 16.



Scale 1/4th 0 5 inches.

(Proceedings Inst. M. E. 1873.)

Fig. 1. *Diagram of Stirling's Engine, 1843.*



(Proceedings Inst. M. E. 1873.)

Fig. 2. *Diagram of Ericsson's Engine, 1853.*

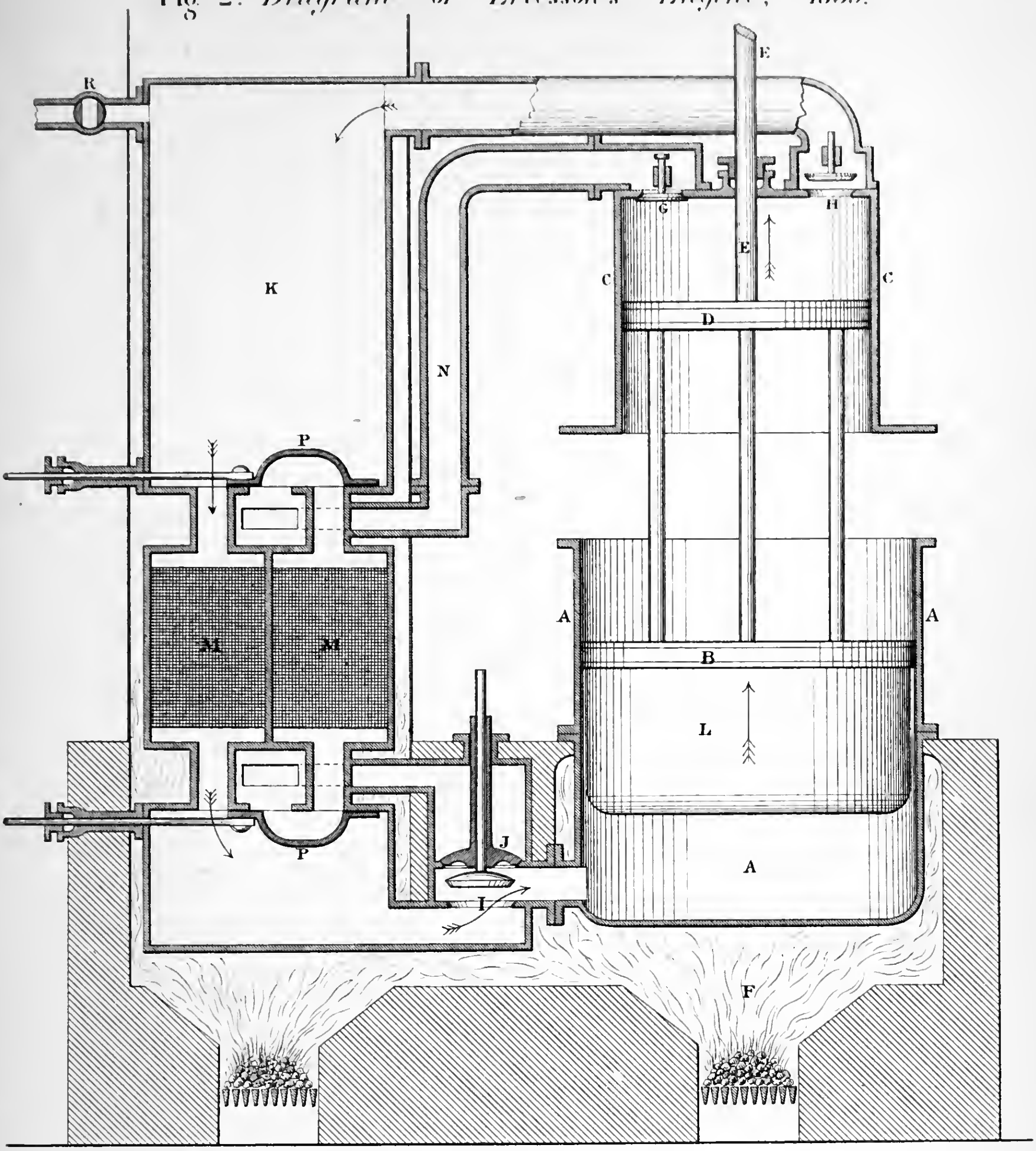
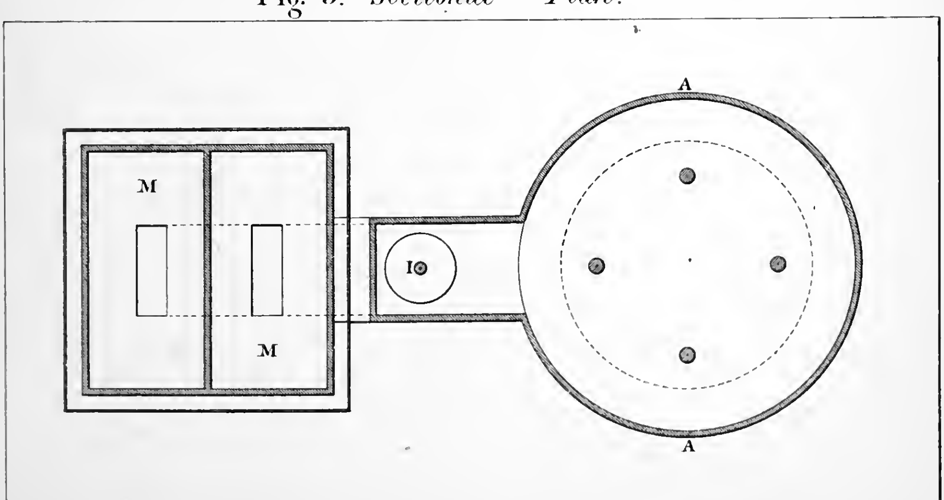


Fig. 3. *Sectional Plan.*



(Proceedings Inst. M. E. 1873.) *Scale 1/120 th.*

HEATED AIR ENGINE.

Wenham's Engine.

Fig. 4. *Side Elevation.*

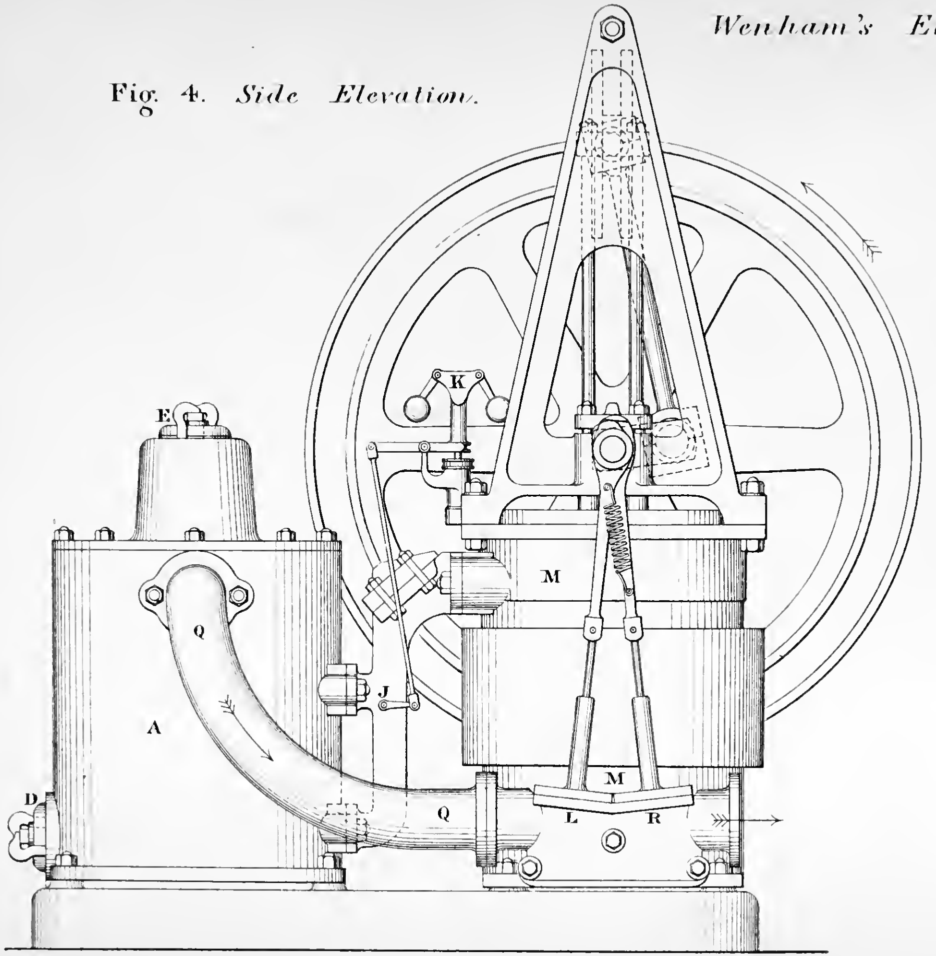
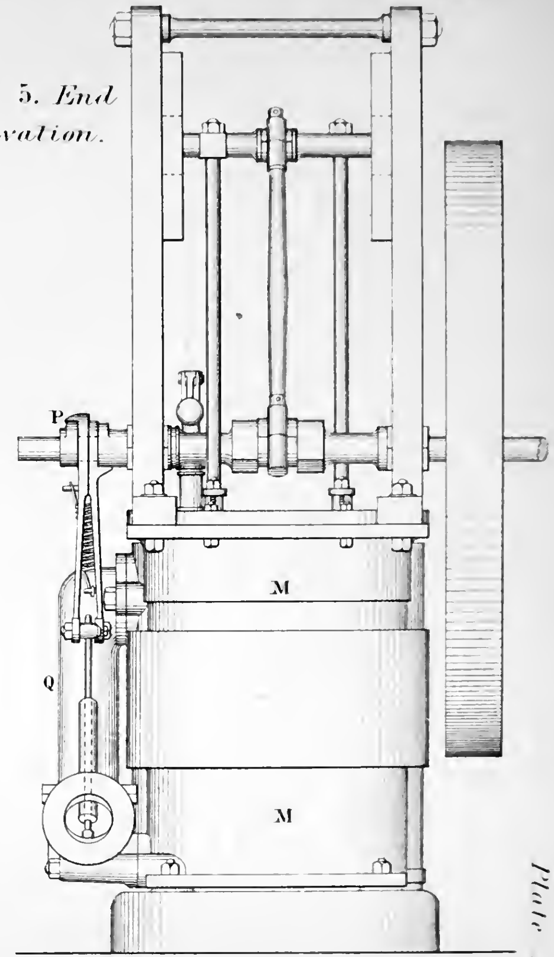


Fig. 5. *End Elevation.*

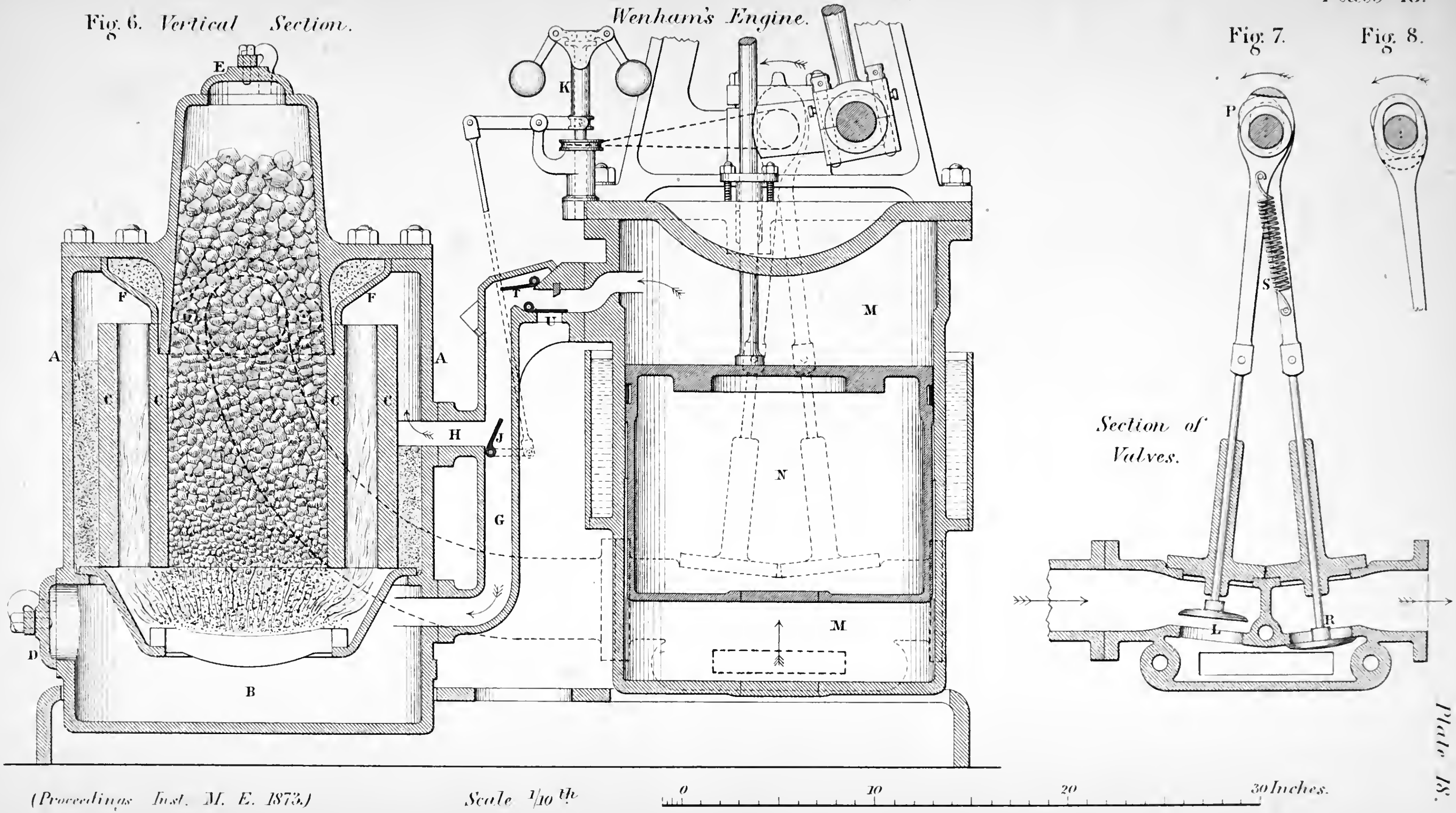


Scale 1/16th. Ins. 12 6 0 1 2 3 4 Feet.

Plate 17.

HEATED AIR ENGINE.

Wenham's Engine.



Scale 1/10 th

Plate 18.

HEATED AIR ENGINE.

Wenham's Engine.

Fig: 9. *Sectional Plan. of Furnace.*

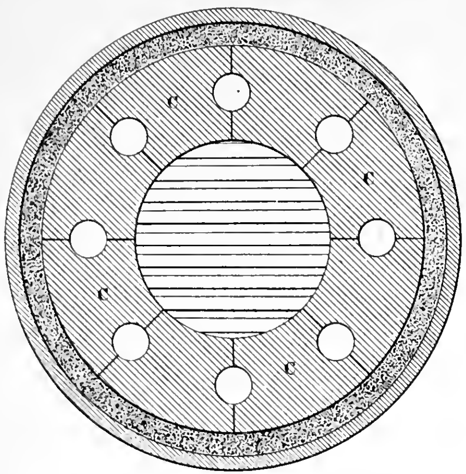
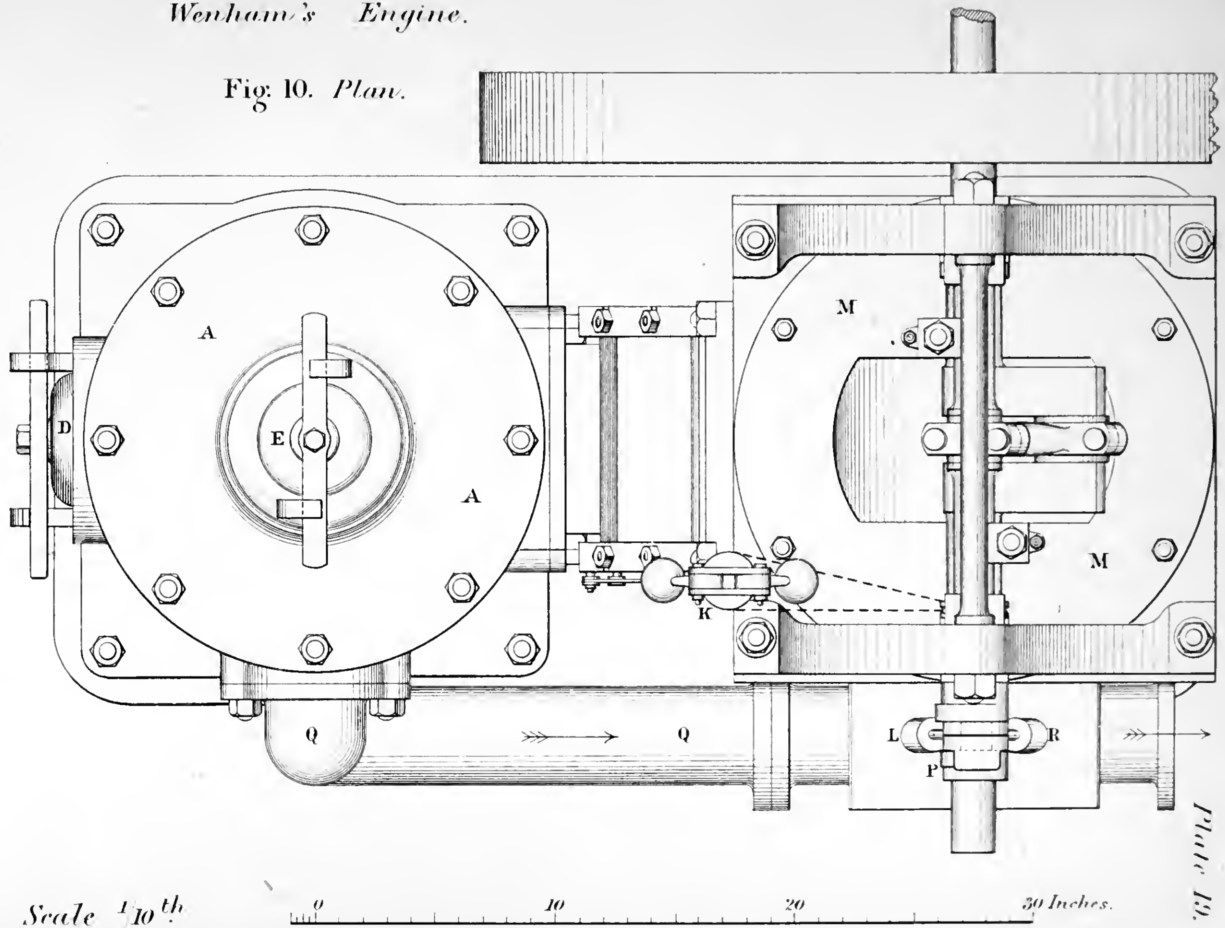


Fig: 10. *Plan.*



(Proceedings Inst. M. E. 1873.)

Scale 1/10th.

Plate 19.

Fig. 11. *Indicator Diagram showing Driving Pressure below piston.*

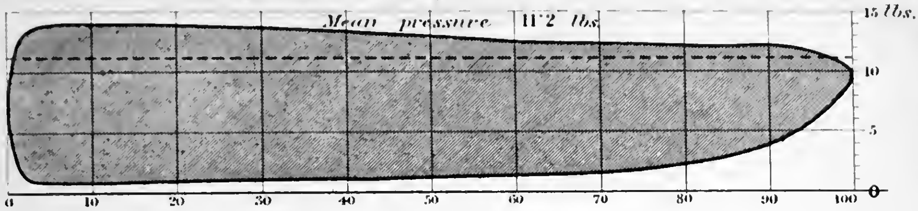


Fig. 12. *Indicator Diagram showing Air Compression above piston.*

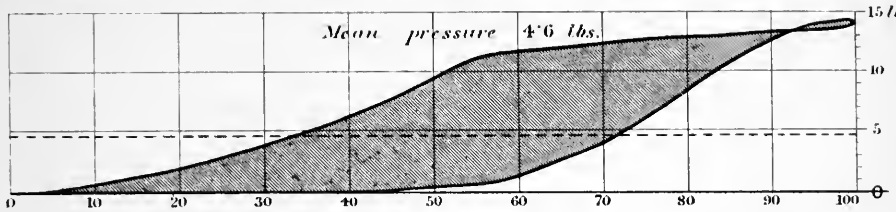


Fig. 13. *Combined Diagram showing Effective Driving Pressure.*

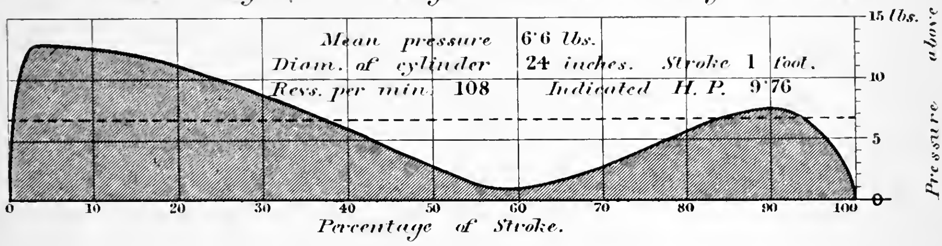
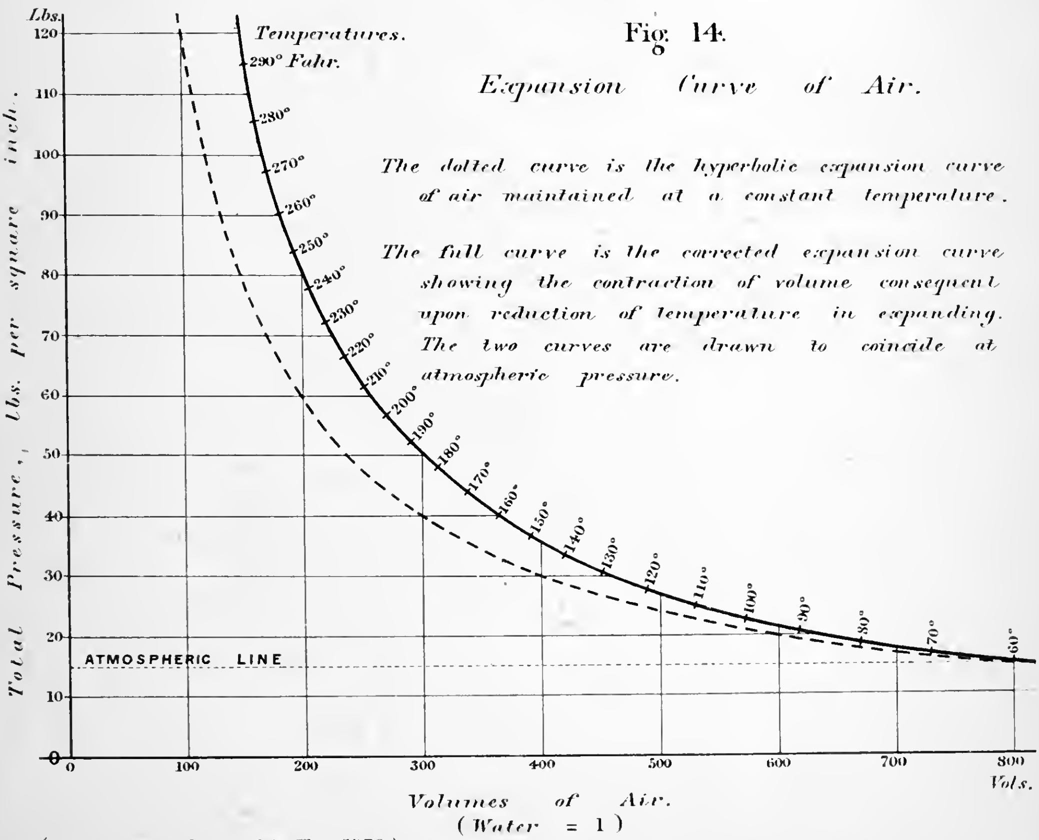


Fig. 14.

Expansion Curve of Air.



The dotted curve is the hyperbolic expansion curve of air maintained at a constant temperature.

The full curve is the corrected expansion curve showing the contraction of volume consequent upon reduction of temperature in expanding. The two curves are drawn to coincide at atmospheric pressure.

(Proceedings Inst. M. E. 1873.)

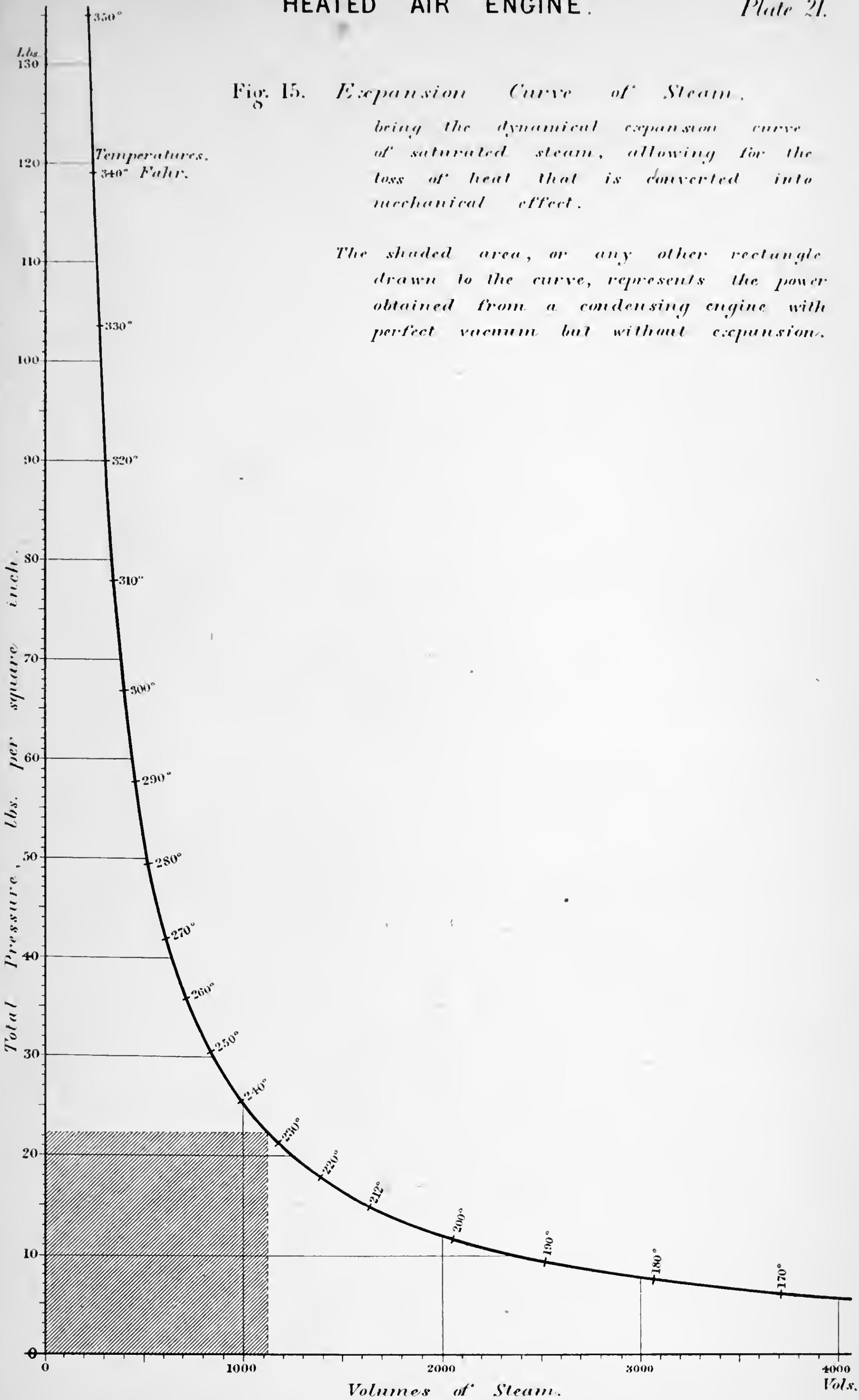


Fig. 15. *Expansion Curve of Steam,*

being the dynamical expansion curve of saturated steam, allowing for the loss of heat that is converted into mechanical effect.

The shaded area, or any other rectangle drawn to the curve, represents the power obtained from a condensing engine with perfect vacuum but without expansion.

(Proceedings Inst. M. E. 1873.)

PROCEEDINGS.

1 MAY, 1873.

The GENERAL MEETING of the Members was held at the Institution of Civil Engineers, London, on Thursday, 1st May, 1873; C. WILLIAM SIEMENS, Esq., D.C.L., F.R.S., President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The PRESIDENT announced that the Ballot Lists had been opened, and the following New Members had been found to be duly elected:—

MEMBERS.

HENRY APPLEBY,	Newport, Mon.
DAVID NELSON ARNOLD,	Birmingham.
THOMAS ASHBURY,	Manchester.
WILLIAM HENRY BECK,	London.
JOHN GREENWOOD BENTLEY,	Manchester.
FREDERICK CLENCH,	Lincoln.
EDWARD FREDERIC CRIPPIN,	Wigan.
JOHN HENRY DAVIS,	Manchester.
GEORGE DOVE, JUN.,	Brigg.
RICHARD HENRY HARRIS,	Whitehaven.
FRANKLIN HILTON,	Workington.
JOHN HOSKING,	Gateshead.
SAMUEL JACKSON,	Bombay.
JOHN GEORGE MAIR,	London.
HENRY MARTIN MORRISON,	Manchester.
EDWIN MUIR,	Rochdale.
RICHARD PEARCE,	Calcutta.

Arthur Henry Wright Radcliffe,	Birmingham.
John Richardson,	Lincoln.
George Robertson,	Exeter.
John Frederick Seddon,	Accrington.
Charles Smith,	Hartlepool.
Joseph Trow,	Wednesbury.
Eric Hugo Waldenström,	Manchester.
Thomas Sipling Wilson,	London.
Charles Frederic Trelawny Young,	London.

The following paper was then read:—

ON THE ALLEN GOVERNOR AND THROTTLE VALVE FOR STEAM ENGINES.

By Mr. FREDERICK W. KITSON, of Leeds.

A steam engine Governor is required to maintain a uniform speed in the working of the engine, whilst variations occur in the amount of work done; and the ordinary Watt governor, although capable of effecting this object with a close approximation to accuracy when the variation in the power is confined within very narrow limits, fails entirely in maintaining the speed of the engine when extensive and sudden changes occur in the resistance to be overcome. In such a case, when half the load is thrown off, the governor forces the engine into a permanently higher speed of running, because the only means by which it can make the corresponding adjustment of the throttle-valve, by closing it so as to supply only steam for half the power, is by the governor balls flying out to a wider circle, and they can only be maintained in that altered position by a corresponding permanent increase of speed in the engine. Also the inertia of the heavy balls requires a considerable variation of speed to take place before they begin to operate, and maintains them in their altered position after the change of speed has ceased.

This defect becomes of serious consequence in some cases, such as in the engines driving rolling mills in iron works, where the whole power of the engine has to be exerted suddenly whilst the iron is passing through the rolls, and the work then suddenly ceases, leaving only the resistance of the friction of the machinery to be overcome. In the case of a mill for rolling solid steel tyres at the writer's works, Monkbridge, the separate engine that drives two sets of tyre rolls has to exert suddenly a power of 550 horse power whilst the hydraulic pressure is put upon the tyre rolls,

and then the engine is suddenly relieved of the whole work excepting the friction of the machinery. With the Watt governor originally used for this engine and fitted with a double-beat equilibrium valve, the speed was maintained uniformly when running light; but when rolling a tyre it was found difficult to keep up the speed, as the momentum of the flywheel became used up before the governor acted sufficiently to put on the pressure of steam necessary for carrying on the work, and the engine was often brought to a stand. To prevent loss from this cause, the engineman had constantly to stand by and handle the throttle-valve, so as to put the steam full on whenever he thought it would be required for carrying the work through; but in doing this a greater quantity of steam than necessary was very frequently put on, thereby causing destructive straining of the engine and machinery.

For regulating this engine the writer has made trial of the Allen Governor, and it has proved thoroughly successful in removing the above difficulty, and has been found completely satisfactory in work. During the time, nearly a year, that this governor has been in work upon the engine, the engineman has had nothing to do with the throttle-valve, and has only had to start and stop the engine, opening the stop-valve to its full extent at starting and leaving it so, as with this governor the engine maintains the required uniform speed so long as there is sufficient steam made in the boilers to do the work. This engine when rolling a steel tyre in the finishing mill has indicated 550 horse power one minute, and only 130 horse power in the next minute, without any change being perceptible except in the rumble of the gearing, the control of the engine being effected by the governor alone, and the stop-valve remaining constantly wide open. The indicator diagrams are shown in Fig. 1, Plate 10; the upper line indicates 550 horse power when rolling a steel tyre, and the lower line 130 horse power when no work was in the mills.

This Governor is the invention of Mr. Huntoon, of Boston, United States, and has been carried out by Messrs. Whitley, of

Leeds, who have supplied the writer with the drawings and description for the present paper. The governor is shown in Figs. 4 and 5, Plate 11, which are side and end elevations showing the governor and throttle-valve with their connection; and in Figs. 6 to 9, Plate 12, are given enlarged sections of the governor.

The governor consists of a small paddle-wheel A with six arms, Figs. 6 and 7, Plate 12, which is driven by the engine at a speed of 350 to 400 revolutions per minute, and revolves within a cylindrical casing B that is filled about two thirds with oil. The casing B is centred upon the spindle of the governor, but turns loose upon it, having at one end a stuffing-box joint C to prevent the escape of the oil, and at the other end an internal socket in which the end of the spindle revolves. The two ends of the casing have a set of radial ribs D D cast upon them on the inside, which nearly touch the edges of the revolving paddles, leaving 1-32nd inch clearance on each side; there is also a set of ribs E E round the circumference of the cylinder, which nearly touch the extremities of the paddles, leaving a clearance of 1-16th inch. The rotary motion communicated to the oil in the cylindrical casing by the rapidly revolving paddle-wheel acts upon these projecting ribs, tending to drag the cylinder round with a force dependent upon the velocity of the paddle-wheel. This tendency of the oil cylinder to rotate is resisted by a weight F, the action of which is illustrated by the diagrams Figs. 2 and 3, Plate 10, in which the weight is shown suspended by a chain coiled round the circumference of the cylinder. The weight is adjusted in amount so as exactly to balance the tendency of the cylinder to rotate when the engine is running at its correct speed; but any increase of speed causes an increase in the rotary force that is communicated to the cylinder, and the resistance of the weight being consequently overcome, the weight is instantly drawn up; the throttle-valve lever being connected to the weight, the valve is closed by the rising of the weight, and further increase of speed in the engine is prevented. In the contrary direction, any diminution of speed in the engine reduces the rotary force below the point that balances

the weight, which instantly falls and opens the throttle-valve wider. As the resistance offered by the weight to the rotation of the cylinder continues exactly the same whilst the cylinder turns round into any new position, the result of any change in the work on the engine will be that the cylinder will shift at once into the new position which gives the particular opening of throttle-valve corresponding to the change of work, so as to maintain a uniform speed of the engine.

Some modification of this action is requisite in practice, to counteract the effect of the inertia of the weight in causing the governor to over-run its true position, in the case of a sudden change in the work on the engine. The weight is therefore made to act upon a spiral, as shown in the diagram Fig. 11, Plate 13, which differs little from the mean circle in the middle of the course, but is extended considerably beyond it at the outer end, so as to increase the leverage at which the weight acts when raised to the extremity of its range, as shown in Fig. 12, and cause it to return at once to its correct position. The opposite end of the spiral similarly acts to check the inertia of the weight in descending, as shown in Fig. 10, by diminishing its leverage at the inner extremity of its range, and so allowing the rotary force to raise it again to its correct position. The spiral is arranged also to counteract the unbalanced pressure tending to close the throttle-valve when nearly shut, which arises from the effect of the current of steam passing through the contracted opening of the valve, and increases in amount as the area of passage through the valve diminishes.

The form of the spiral and extent of its deviation at the extremities from the mean circle are varied according to the extent and suddenness of the fluctuations in the amount of the work done by the engine; and a comparative diagram of the curves in two different instances is shown in Fig. 13, Plate 13. In the case of a cotton-mill engine the total resistance to be overcome by the engine is exposed to but little fluctuation in regular work and continues very uniform, and the full line in Fig. 13 shows the spiral employed for an instance of this kind in the governor at Messrs. Taylor's

cotton-mill, Wigan. The dotted curve shows the spiral used where the engine is exposed to considerable and sudden fluctuations of work.

The spiral is formed by a scroll G, Figs. 6 and 8, Plate 12, which is centred upon a short axis fixed in the end of the oil cylinder in line with the governor spindle; this axis is supported by a bearing in the governor frame. A chain carried round the scroll is attached to the suspended weight F, which consists of a set of disc weights of different thicknesses; these give the means of readily adjusting with great accuracy the speed at which the engine is to run. By removing a weight the engine speed is diminished, as a lower velocity of rotation of the paddle-wheel is then sufficient to balance the resistance of the weight; and by adding a weight the engine speed is increased correspondingly. The amount of weight that is ordinarily supported is from 6 to 12 lbs., according to the size of the governor, and it acts at a radius of 2 inches. A small pinion H, fixed on the axis of the oil cylinder, gears into a toothed sector on the upper end of a lever L, which is connected at the bottom to the throttle-valve; and the extreme range of motion of the oil cylinder, amounting to about two thirds of a revolution, gives a range of motion of the throttle-valve from full open to full shut. The pinion H is connected to the scroll G by means of a disc K, shown in Fig. 9, having a slot in it, through which passes a set-screw J fixed in the scroll; this allows of adjusting accurately the position of the scroll in relation to the required opening of the throttle-valve.

The governor spindle works through a stuffing-box C, Fig. 6, in the end of the oil cylinder, but the friction is so much reduced by the constant supply of oil from the interior, that a small pressure from the gland is sufficient to keep the packing tight, and prevent anything more than a very slight leakage of oil; this is caught in a cup N provided in the frame, and is drawn off occasionally, and the cylinder filled up again when required through a screwed plug-hole P. But the loss of oil is so small, that even in the case of the governor at Monkbridge Iron Works, which is exposed to all

the dust of the rolling mill, the oil cylinder did not require any supply of oil until after four months' work; and the governor of the shop engine at Messrs. Whitley's works has been a year and a half in constant use, and has only once required a supply of fresh oil; the oil escaping from the stuffing-box and caught in the cup has been returned to the cylinder once every two months.

For maintaining the delicacy of action of this governor, it is requisite that its friction should be small and uniform in amount. The friction is reduced to a small amount by the circumstances that a very small spindle can be used, only $\frac{5}{8}$ inch diameter in the governor for the 500 horse power rolling-mill engine, and the bearings work in a bath of oil. Uniformity in amount of friction is obtained by the use of a special packing in the stuffing-box, consisting of a series of separate rings, each made of a small roll of canvas steeped in tallow and covered with paper; a light pressure of the gland is found sufficient to keep this packing tight enough to hold the oil in the cylinder, and when properly adjusted at starting the packing is found to have scarcely any appreciable wear; the original packing continues in good order after one and a half year's work in the governor of Messrs. Whitley's shop engine.

The governor at the writer's works was originally driven by a belt from the flywheel shaft, but gearing has now been substituted, and is found to work very well, driving a light intermediate shaft at 240 revolutions per minute, from which the speed of the governor spindle is got up to the required number of revolutions by another pair of wheels. The governor is found to act quite as sensitively when driven by gearing as with a belt, and the danger arising from the belt breaking or slipping is avoided; at the same time the strain upon the governor spindle, consequent upon the drag of the heavy belt from the flywheel shaft, is removed.

The Throttle-Valve shown in Figs. 14 to 16, Plates 13 and 14, is a modification of a double-beat valve, which is arranged to work with very little friction and resistance, and reduces to a small amount the unbalanced pressure from the current of steam that tends to close the valve when nearly shut. The two valve-seats

are bored out parallel and of the same diameter, and the valve R just enters these seats when closed, entering only 1-16th inch and then resting on a stop; sufficient allowance is made in the diameter of the valve to prevent its binding from expansion. This valve, if not absolutely steam-tight, only allows so very small a quantity of steam to pass when closed, as not to have any effect upon the engine. The valve is in equilibrium, except to the extent of the difference of pressure per square inch upon the top and the bottom due to the motion of the steam in passing the valve; this difference is materially reduced by the valve being made with a tubular passage through the centre. The valve is lifted by a lever S, fixed upon the spindle T inside the valve-box, and working in a loop on the top of the valve. In the stuffing-box of the valve-spindle the same packing is employed as for the governor spindle, as shown in Fig. 14; by this means the friction of the valve-spindle is reduced to a small amount, and is kept very uniform, so as not to interfere with the delicacy of action of the governor. The spindle T has a long parallel bearing to ensure steadiness and durability, and the lifting lever S is fixed upon it by a taper screwed pin; the whole is readily accessible for removal on taking off the cover, when the valve can also be withdrawn for cleaning or examination. The lever L carrying the toothed sector that is acted upon by the governor pinion H, Figs. 4 and 5, is fixed direct upon the valve-spindle T, so that the connection is direct from the governor to the throttle-valve, thus avoiding the friction of intermediate levers, and making a very compact arrangement.

A smaller size of throttle-valve can be used with this governor than with the ordinary ball governor, on account of its more complete and prompt action. This is an advantage of importance, as it is objectionable to employ a valve larger than is absolutely necessary for the requirements of the engine; and a smaller valve that opens to its full extent has a much better control over the engine than one of larger size continually hovering over the closing point. The best results have been obtained when the diameter of the valve is one fifth to one sixth of that of the engine cylinder, for high-pressure engines with a moderate degree of expansion. In the

case of engines working at a high rate of expansion with steam of considerable pressure, a smaller proportion of valve is sufficient; and in compound condensing engines having full boiler pressure through the greater portion of the stroke, a somewhat larger proportion is advantageous. In the case of the tyre-mill engine at Monkbridge, which has a 36 inch cylinder with a piston speed of 550 feet per minute, a 5 inch throttle-valve is employed with the new governor; and this engine with 50 lbs. boiler pressure had an initial pressure of 49 lbs. in the cylinder when indicating 550 horse power, showing that the throttle-valve was large enough in area.

Five of these governors have now been applied at the writer's works since the original one in the tyre mill that has been referred to, and these are all working with complete satisfaction; they have given no trouble, and the refilling with oil and adjusting the stuffing-box packing have been done so seldom as to be found no objection in practice.

One of these governors is applied to the engine driving a large reversing Plate Mill, which had previously a ball governor and equilibrium throttle-valve similar to those of the tyre-mill engine, and had the same fault, requiring the throttle-valve to be "handled" whenever any heavy work had to be done. The steam can now be turned full on at starting, and the engine will go through any work that is put upon it without requiring the attention of the engineman at the throttle-valve. It has been found in this case that the strain upon the gearing is not so sudden as when the old governor was attached.

Another of these governors is applied to the engine of a 10 inch Rod, Guide, and Hoop Mill, in which the rolls are driven through a pair of spur wheels, the flywheel being on the second-motion shaft. With the previous ball governor much trouble was experienced from the flywheel over-running the driving shaft when the engine was lightly loaded, thereby causing great backlash on the wheels when a piece of iron was put into the rolls, and necessitating a frequent renewal of the gearing, as the teeth would not stand the hammering they were subjected to; other parts of the machinery and also the

engine-house suffered. The new governor however has not only stopped the backlash and its attendant evils, but by making the speed of the engine much more uniform it enables a greater weight of iron per week to be got out than formerly.

The engine of another Rod and Guide Mill has its speed maintained uniform by one of these governors, when rolling both large and small sized rods; but the working of the engine with the previous ball governor was very irregular, using considerably more steam than at present, and doing less work.

A large Plate Shears, in which the shear slide is unbalanced, has one of these governors applied to it, and the speed is kept quite uniform when shearing and when running light; and another of the governors has been applied to a small pumping engine, and is found to render good service by keeping the pump at a regular speed, unaffected by the slack at the end of each stroke.

These governors are now in operation at several iron and steel works, paper mills, cotton mills, and other works in this country, and have been found to give very satisfactory results.

Mr. J. Whitley exhibited a working model of the governor, showing its action, together with specimens of the separate parts and of the throttle-valve. He stated that the first of these governors brought over to this country from America had been in constant use on the engine at his works in Leeds for nineteen months, without having lost so much as a cubic inch of oil during the whole time, the same oil being in use as at first. The first governor made in this country was put upon the rolling-mill engine at the Monkbridge Iron Works, and it proved so entirely satisfactory in operation that several more of the governors were then applied to other engines at the same works; and the governor was now in use at many other works in this country and on the

continent, being found completely successful in keeping the speed uniform up to the maximum power that could be maintained by the boiler. With an engine speed of from 60 to 100 revolutions per minute, a variation of only one revolution per minute above or below the proper speed was instantly corrected by the governor diminishing or increasing a little the supply of steam to the engine; and so imperceptibly was this done that it was impossible to detect any variation in the speed except by watching the rising or falling of the governor weight. One modification that had been made in the construction of the governor in this country was the addition of the set-screw and slotted disc for adjusting the spiral scroll in the proper angular position relatively to the pinion working the throttle-valve lever, so as to make the governor weight act at exactly the proper leverage upon the scroll when the engine was running at its normal speed. Another improvement was the addition of a thin casing of gunmetal upon the steel spindle working the throttle-valve; the original governor supplied from America had a plain steel spindle, which became corroded in the stuffing-box and interfered with the working of the throttle-valve; this was taken out and replaced by a spindle covered with gunmetal, and there had since been no further difficulty from corrosion. The only difficulty that had occurred in the working of the governor had been in one or two instances where the stuffing-box of the valve spindle had inadvertently been screwed up too tight by the attendant, and the excess of friction had then interfered with the free working of the throttle-valve; but this had been immediately rectified by simply slackening the gland of the stuffing-box. With that exception nothing had occurred to interfere with the perfect working of the governors already in operation. The name by which the governor was known was that of the proprietor in Boston, instead of that of the inventor Mr. Huntoon.

Mr. B. Walker said that at his works in Leeds one of these governors had been in use about six months upon the engine driving the machinery of the works; it had given no trouble and continued working with great satisfaction. The load upon the engine was

very variable, being thrown on and off rapidly, but the speed was always kept practically the same by the governor. Previously an ordinary ball governor very carefully constructed had been employed, with a good throttle-valve; but the present governor had proved much superior in action. In the case of an engine which he had lately supplied to a rolling mill, furnished with this governor and throttle-valve, the governor and valve had been returned without trial, as it was believed to be useless to attempt to control a rolling-mill engine by a governor, because the ordinary governor was known to be so incapable of acting promptly enough for controlling the engine under the very sudden changes of load which occurred in those cases, that it was the practice in many instances to regulate the steam supply by hand, without using a governor; all need of hand control however was obviated by the employment of the improved governor. He considered this governor the best he had seen, as it was the most sensitive and the least likely to get out of order. He had seen it in use upon the engines at the Monkbridge Iron Works, where it was working with complete success, and he considered it was especially useful for engines driving rolling mills, because the load in that case was so variable that it was impossible for the engineman to regulate the supply of steam promptly enough, and any want of attention on the part of the man handling the throttle-valve caused either a deficiency or an excess of steam. The use of the governor prevented the possibility of such accidents as had frequently occurred from the engine running off under an excess of steam when the load was suddenly diminished, and causing the flywheel to break in pieces from excessive speed.

The President enquired whether the governor had been tried with the ordinary disc throttle-valve.

Mr. B. Walker replied that the governor at his works had the cylindrical double-beat valve shown in the drawings, but he saw no reason why it should not be used with the ordinary disc throttle-valve, provided the valve were made with sufficient accuracy, so as to work easily and without jamming itself when closed suddenly. A disc throttle-valve as usually made had too much friction to be

suitable for so sensitive a governor, and would be liable to stick if closed with a jerk; and this governor had hardly sufficient power to move such a valve promptly enough for preventing a considerable variation of speed in the engine. The hollow double-beat valve had the advantage of being comparatively small in size and with scarcely any friction, so that it required very little power to move it and was easily worked by the governor; and the trifling leakage of steam past the valve when closed was not enough to be of any consequence.

Mr. F. J. Bramwell asked why there was any need for the stuffing-box, as it appeared to him the weak point of the governor was that its efficiency might be impaired by screwing the stuffing-box too tight; and he suggested that this might be obviated by placing the governor spindle vertically, instead of horizontally; in that case the spindle would pass out quite freely through a boss in the top of the cylindrical casing containing the oil, without the need of any stuffing-box or packing.

The President remarked that the chain from the spiral on the governor spindle to the weight would then have to be led off horizontally over a pulley.

Mr. J. Whitley said it was not with the stuffing-box of the governor spindle that any difficulty had occurred from the packing being screwed up too tight, but with that of the throttle-valve spindle. In the event of the stuffing-box of the governor spindle ever being accidentally screwed up too tight, this would at once be rendered apparent by the cylindrical casing of the governor being carried round too far and so closing the throttle-valve; in practice the stuffing-box gland was only screwed up so slightly that no appreciable friction was caused. The stuffing-box of the valve spindle had in some cases been dispensed with by turning a small conical shoulder upon the spindle, this shoulder working in a corresponding conical seat turned in the socket through which the spindle passed in the valve-box; the spindle was then put in from the inside of the valve-box, and the conical joint was made steam-tight by the outward pressure of the steam. The best plan however he thought was to have an ordinary stuffing-box, and it

was a simple matter to take care that the packing was never screwed up too tight to interfere with the free working of the valve; the special packing that was used, as described in the paper, was found quite satisfactory.

Mr. H. Brogden observed that the employment of a liquid had been one of the main features also in the chronometric governor of Mr. Siemens, of which a description had been given at a former meeting of the Institution (see Proceedings Inst. M. E. 1866 page 19); and he had had one of those governors at work for some years upon an engine driving a guide mill at the Tondû Iron Works, South Wales, with the same advantageous results that had been mentioned in connection with the governor now described. The governor at these works had given no trouble whatever, and had not required any attention; the speed of the engine was readily regulated to any number of revolutions required by simply altering the quantity of liquid in the chamber of the governor, and this was a great advantage for engines where the speed had to be varied frequently.

Mr. L. Olrick considered the governor now described was a simple and effective one, and could be applied where more complicated governors would not be suitable; and it appeared to possess several points of merit, that would be appreciated in practice, one of which was the very neat arrangement of throttle-valve used in connection with the governor. In some cases in which efficient governors had been applied, they had suffered from having to deal with a common butterfly throttle-valve that had 90° range of angular motion, and when shut leaked to a very great extent. No doubt the range might advantageously be reduced to 45°, but this alteration could only be accomplished by putting in a new throttle-valvebox, which was not always possible or convenient to be done; as the valve when shut stood then at an inclination of 45° across the steam pipe, it was necessary that the disc should be made heavy enough to ensure sufficient strength, for if made too light the disc might be broken by being closed violently by the governor. Another objection to such valves was that unless they were fitted when hot, which as a rule was not done, he did not believe they could be made thoroughly steam-

tight. In comparison with the ordinary butterfly throttle-valve therefore, the cylindrical valve now described seemed to him a great improvement; and next to a good governor a good throttle-valve was of great importance. In the governor itself he did not think any practical difficulty could arise from screwing up the stuffing-box of the governor spindle too tight, because the packing was always kept thoroughly lubricated by a little oil leaking out from the cylindrical casing. One improvement which he thought might be made would be to remove the weight from the governor and substitute a spring instead; for marine purposes this would be compulsory, and he thought it would be equally advantageous for land engines. Although the governor now described appeared to him to be one of the best he had seen for all practical purposes, he considered the differential governor with one arm invented by Mr. Siemens was a nearer approach to perfection in maintaining the speed unaltered, on account of being dependent upon the time of a pendulum, which rendered it impossible for the engine to go beyond the prescribed number of revolutions per minute; and he was surprised that that governor was not found in all spinning mills, as it would effect so great a saving by preventing waste of steam and breakage of threads through variations of speed. As an illustration of the extreme sensitiveness of that governor he might mention that in one instance where it was in use the crank shaft broke while the engine was running at 70 revolutions per minute, and though the whole of the work was thus suddenly thrown off, the number of revolutions only increased to 71 per minute.

The President considered the governor described in the paper was remarkable chiefly for its simplicity, and it appeared to have been found to answer well in practice. Reference having been made to his own liquid governor in connection with that now described, it was to be observed that, though both of them dealt with liquid resistance, they did so in a different manner. In the governor now described the power to act upon the throttle-valve was obtained in an indirect way; the rotating paddle-wheel did not act directly upon the valve, but impelled the oil against the corrugations in the casing containing it, and the impact tended to make the

casing rotate in the same direction; the casing however was held back either by a dead weight, or, as had been suggested, by a spring, or really by a combination of a dead weight and a spring, because a weight alone would over-run itself if acting at a constant leverage. When therefore the velocity of the rotating paddle-wheel was so proportioned to the weight as just to hold the latter suspended, a balance was established; but as soon as the engine exceeded its normal speed, an additional amount of impact was created in the oil casing, which accumulated until it had sufficient power to overcome the resistance of the throttle-valve and of the stuffing-box on the valve spindle. This power however to move the valve was not large, in comparison with the total force acting to support the governor weight at the normal speed; if for instance 100 revolutions of the paddle-wheel per minute sufficed to balance a weight of 10 lbs., then a variation in speed of two or three revolutions per minute would affect the weight to the extent of only a small fraction of a pound, which would accordingly be the limit of the force available for moving the valve. It was therefore an object of primary importance that the frictional resistance in the valve and stuffing-box should be as much reduced as possible; and this appeared to have been accomplished successfully by the construction of throttle-valve now described. If this delicacy of action could be maintained, the governor would be applicable no doubt to engines subjected to frequent and sudden alterations of load. His own liquid governor, described at a former meeting some years ago (see Proceedings Inst. M. E. 1866 page 19), consisted of a cup of parabolic section revolving upon a vertical spindle within a vessel partly filled with oil or water; and by the rotation of the cup, which was open at top and bottom, the liquid was caused to rise up the sides of the cup, but did not overflow the edge until the speed of rotation had reached a certain limit. Up to the moment of the cup overflowing, it acted only as a flywheel, but at the moment it overflowed it became a pump, drawing in liquid through the central aperture at the bottom and discharging it over the top edge; the external surface of the cup and the interior of the vessel in which it revolved were provided

with a series of radial vanes, and the overflowing stream of liquid from the cup impinged successively upon the stationary vanes and upon those on the revolving cup, thus presenting a practically uniform resistance to its rotation. The cup was driven by the engine through differential gearing, with which was also connected the weighted lever of the throttle-valve, this constant weight acting always to maintain the uniform rotation of the cup. Although a weight was thus employed both in his own and in the Allen governor, there was an essential difference of action between the two, inasmuch as in the Allen governor the throttle-valve had to be moved by only a fractional portion of the suspended weight; whereas in his own governor the difference between the uniform rotation of the cup and the varying speed of the engine acted direct upon the valve through the differential gearing, the uniformly rotating cup serving as a fulcrum or abutment, while the actual amount of the weight upon the throttle-valve lever was immaterial, except as regarded the original determination of the frictional resistance for the cup. It would thus be seen that there was indeed more similarity in appearance between the two governors than really existed in their modes of action; and it was clear that the throttle-valve now described in connection with the Allen governor must be looked upon as an essential part of the governor, the prompt action of the governor depending upon the ease with which the valve could be moved with a slight amount of force. Owing to the great simplicity of this governor, and the careful manner in which the mechanical details had been worked out, he had no doubt it would meet with success in its application.

He proposed a vote of thanks for the paper, which was passed, to Mr. Kitson, who he regretted was prevented by illness from being present at the meeting.

The following paper, communicated through the President, was then read:—

ON WENHAM'S HEATED-AIR ENGINE.

BY MR. CONRAD W. COOKE, OF LONDON.

The history of the Heated-Air Engine dates as far back as the year 1807, when Sir George Cayley invented his engine. This was followed by Stirling's engine, which was applied in 1818 to pumping water from a quarry in Ayrshire; but owing to the slight construction of the heating vessels, which were of boiler plate, the bottoms of the vessels were in a short time burnt through, and the invention was for a time abandoned. In 1827 however it was improved by the employment of compressed air, instead of air at atmospheric pressure, thereby reducing the size of the working parts without diminishing the power of the engine.

A diagram of Stirling's engine is given in Fig. 1, Plate 15. The two heating vessels A A have their lower ends exposed to the fire F, their upper ends being kept cool by means of water circulating round them. They contain the two plungers or displacers B B, attached to the opposite ends of a horizontal beam D, which is oscillated by a crank and connecting rod from the main shaft of the engine; these displacers do not fit the heating vessels, but have an annular space left all round them. The working cylinder C, containing a close-fitting piston, communicates at top with one of the heating vessels, and at bottom with the other. By the alternate upward and downward movement of the plungers B B the air in the heating vessels is displaced, and sent alternately to the bottom or heated part and to the top or cool part of the vessels; the air in either vessel thus becomes heated or cooled according as the plunger is respectively at the top or bottom of its stroke. A difference of pressure must therefore take place in the spaces above and below the working piston, which will consequently

move in the direction of the lower pressure; and in doing so it changes the position of the plungers, and the operation is reversed. Two of these improved engines were constructed, one with a cylinder 12 inches in diameter and 2 feet stroke, which made 40 revolutions per minute and worked up to 21 horse power, consuming $2\frac{1}{2}$ lbs. of coal per indicated horse power per hour; and another in 1843 with a cylinder 16 inches in diameter and 4 feet stroke, making 28 revolutions per minute and giving 45 horse power. The latter was the celebrated engine of the Dundee Foundry, and did all the work of that establishment for upwards of three years, during which period no other motive power was employed. It was laid aside however at the end of that time owing to the failure of the heating vessels, which could not stand the heat they were exposed to.

While Stirling's improved engine was being brought out in this country, Ericsson produced his engine in America; and so much public confidence was obtained for it that a gigantic pair of marine engines of 600 horse power upon his principle were constructed for propelling the ship "Ericsson."

In all these heated-air engines, with the exception of Cayley's, a Regenerator, or more correctly speaking a Respirator, was employed for utilising that portion of the heat which would otherwise have been thrown away with the exhaust air; and this was the special invention of Dr. Robert Stirling. The regenerator consisted of a passage or chamber, filled in some instances with thin metallic plates or gratings, in some with copper wire or gauze, and in others with thin metallic tubes. Through this chamber the exhaust air was made to pass, and while traversing the interstices it deposited there a portion of its heat; the cold air subsequently introduced, traversing the regenerator in the opposite direction, took up the heat left in the metal. By this means the heat that would otherwise have been thrown away in the exhaust air was utilised for increasing the temperature of the incoming supply of air. In Ericsson's large engine the regenerator presented a heating surface of 4,900 square feet, and the copper gauze of which it was composed weighed 33,000 lbs. By this means it was expected to get back with the

incoming air all the heat expended for working the engine, with the exception only of what was lost by conduction and radiation of the working parts: an idea bordering very closely upon perpetual motion. The heating apparatus was consequently made so inadequate to the requirements of the engine that this was the principal cause of its failure; moreover the metallic heating surfaces were in a short time destroyed in consequence of their direct exposure to the fire.

A diagram of Ericsson's engine is shown in Figs. 2 and 3, Plate 16. The working cylinder A is open at the top to the atmosphere and heated at the bottom by a furnace F, and is fitted with an air-tight piston B. Above it is placed the cylinder C of the air-pump, which is open at the bottom to the atmosphere, and has its piston D connected to the working piston B by four or more piston rods. The motion of the working piston B is transmitted to the machinery by the piston rod E. The air-pump draws in a supply of air through the inlet valve G, and discharges it through the outlet valve H into the receiver or reservoir of compressed air K. Underneath the piston B is attached a hollow box L filled with fireclay or other slow conductor of heat, the object of which is to protect the cylinder and piston from the more direct action of the heat. The cylinder inlet valve I, opened and closed by a cam, makes a communication between the reservoir K and the working cylinder A through one half of the regenerator M, which is a box containing laminæ of copper wire gauze; a similar outlet valve J opens the cylinder A to the exhaust N through the other half of the regenerator M. The action of the two halves M M of the regenerator is reversed periodically by means of the slide-valves P P after about every fifty strokes of the engine.

The working of the engine is as follows. The receiver K having been charged with air by a hand-pump through the pipe R to a pressure of about 10 lbs. per square inch above the atmosphere, the cylinder inlet valve I is opened; and air being thus admitted to the cylinder A through one half of the regenerator M, the piston B rises, and after a portion of the stroke has been performed, the inlet valve I is closed and the admission of air cut off, the remainder of the

stroke being performed by expansion of the air by heat. During the upstroke the air-pump piston D forces a fresh supply of cold air into the receiver K for the next stroke. During the return stroke the cylinder outlet valve J is kept open, and the air is driven out of the cylinder A through the other half of the regenerator M and through the exhaust N into the air-pump cylinder C, depositing in its passage through the regenerator M the greater portion of its heat in the copper gauze, from which when the slide-valves P P are next reversed the heat is taken up by the incoming air from the receiver K.

The engines that have been described worked with great economy of fuel; but it is evident that to heat a bad conductor of heat, such as atmospheric air, large absorbent surfaces must be exposed to the fire, otherwise the amount of waste heat escaping into the chimney would be very great. The fact that so large a heating surface is required, and the impossibility of preserving metal plates constantly exposed to a very high temperature, and of maintaining them free from fracture and with tight joints, have caused engines upon that system to be abandoned.

The class of heated-air engines of which that forming the subject of this paper is a type consists of those in which the fire is enclosed, and fed by air pumped in beneath the grate in sufficient quantity to maintain combustion, while by far the largest portion of the air enters above the fire, to be heated and expanded; the whole, together with the products of combustion, then acts on the piston, and passes through the working cylinder; and the operation being one of simple mixture only, no heating surface of metal is required, the air to be heated being brought into immediate contact with the fire. The first successfully working engine on this principle was Cayley's, in which much ingenuity was displayed in overcoming practical difficulties arising from the high working temperature. The furnace was arranged so that the air pumped in could be conveyed above or below the fire as required; and before reaching the fire the air in its passage was conducted round an annular space between the firebrick lining and the outer casing of the furnace, so as

to keep the exterior as cool as possible. The cylinder was surrounded by a water belt to avoid an excess of heat that would injure the packing of the piston. The cold air for working the engine was pumped in by a separate air-pump. One of these engines was kept at work for many months to test its capabilities: for economy of fuel compared with the work done it surpassed any form of steam engine known at that time; but the joints caused great trouble, and the cylinder and the piston packing were rapidly destroyed by the dust and particles of grit from the fuel, which acted as a grinding material and rendered lubrication impossible. An attempt was made to filter the air before entering the cylinder, by means of sheets of wire gauze; but these either gave way or were soon choked up, and so became useless.

The plan of enclosing the fire in the mass of air to be heated involves the utmost degree of economy, as there is nothing whatever lost in the absolute heating, and the products of combustion, varying in quantity according to the fuel employed, also add to the bulk of the mixture. These principles are embodied in the heated-air engine forming the subject of the present paper, which is the invention of Mr. Francis H. Wenham, the inventor of the binocular microscope, whose researches and inventions in many branches of science are of so much value. In this engine, which has been very successful for small sizes, a peculiar feature is that no separate air-pump is used, the top of the working cylinder itself being employed for that purpose. This is not a new idea, as Ericsson proposed utilising the top of the working cylinder in that way; but he never carried it out practically. The air-pump however must necessarily be of less capacity than the cylinder according to the degree of expansion required to be given by heating the smaller volume of air pumped in; and means had consequently to be devised for diminishing the capacity of the air-pump with the same diameter of cylinder, so that one piston packing might serve for both air-pump and working cylinder. This difficulty was overcome by the President of the Institution, Mr. C. William Siemens, who diminished the air-pump space by attaching to the piston a hollow trunk working through a

stuffing-box in the cylinder-cover. Thus if the trunk were made one half the diameter of the cylinder, it would abstract one fourth from its capacity; and such an arrangement was employed in Mr. Siemens' regenerative steam engine, which would also work as an air engine or with air and steam combined.

Wenham's engine of one horse power is shown in Figs. 4 to 10, Plates 17 to 19. One of its special features is the furnace or air heater A, shown in section in Figs. 6 and 9, in which perfect combustion is obtained from ordinary smoking and bituminous coal; and coal of that description is preferred for this engine. The ashpit B or compartment under the grate is separated from the upper part by a moderately air-tight diaphragm, so that the air that is allowed to enter the ashpit is compelled to pass up through the firegrate. Above the grate is an annulus of segmental firebricks C C, shown in the sectional plan, Fig. 9; these bricks are made with semi-cylindrical grooves at their joints, so that when placed together, the centre forms a cylindrical hopper containing a store of fuel sufficient for several hours' consumption, and the grooves at the joints form a series of vertical flues or channels through the bricks. The column of coal descends as it is consumed on the furnace bars, and the air entering from the ashpit comes into contact with nothing but coal in a state of intense ignition; all the products of combustion have accordingly to pass through the ignited portion, and the channels or flues in the firebricks being also white-hot, no unconsumed products or smoke can escape through them. The furnace has a cover D in front of the ashpit, by which it can be hermetically closed; and there is a similar cover E at the top for filling the coal hopper. The products of combustion after leaving the channels of the firebricks C are met by a baffle plate F backed with fireclay, which prevents the cover of the furnace from getting unduly hot. The space between the firebricks and the outside shell of the furnace is filled to a level a little below the air passage leading to the cylinder with a slow conductor of heat, such as powdered brick or ashes, leaving an air space above that level.

There are two inlet air passages G and H, Fig. 6, for admitting the cold air to the furnace; the passage G conducts the air into the ashpit below the fire, and the other H leads above the fire; at their junction is placed a swing valve J, by which more or less of the air is directed below or above the fire. If all the air be directed below the fire through the passage G, the combustion will become very intense; the heat and consequent expansion of the air will become correspondingly great, and the engine will gain in power and speed. If on the other hand all the air be directed above the fire through the passage H, a very dull fire will be the result; the air will be comparatively cool, and will be less increased in volume, and there will be a diminution in the power of the engine. This difference of power is found to take place so instantaneously that the regulation of the air distribution serves as a very effective means of regulating the speed of the engine, and the governor K is consequently attached to the lever of the swing valve J: this arrangement is found to act so perfectly that no other regulation for speed is required, and it gives the advantage that the combustion of the coal is exactly proportioned to the amount of work performed.

The engine is of the vertical form, having two piston rods with the main or crank shaft running between them, as shown in the plan, Fig. 10, Plate 19; and in order to save space and render the cylinder M as compact as possible, the cylinder cover is made with a segmental recess or depression in which the crank passes, as shown in Fig. 6. The engine is single-acting, the upstroke only being made by the pressure of the heated air below the piston N, and the engine is carried through the downstroke partly by the expansion of the cold air compressed above the piston in the upstroke, and partly by the flywheel. The heated air from the furnace passes along the curved pipe Q, and is admitted at the bottom of the cylinder by the lifting valve L, which is opened by a cam P on the main shaft, as shown in Fig. 7; a lifting valve is required to be used, as a slide-valve will not answer. The exhaust valve R is of similar construction, and is also opened by another cam, as shown in Fig. 8; and both valves are closed by the spring S.

In this engine the protecting drum under the piston N, Fig. 6, which was first brought out in America, is adopted for preserving the working surfaces of the cylinder and piston from the wearing action of the solid products of combustion. This drum is useful only in a single-acting vertical cylinder where the working pressure acts only on the underside. It is simply a prolongation of the piston, in length exceeding by a small extent the stroke of the piston, and is a little less in diameter than the cylinder, leaving a small annular space between the two. The packing ring of the piston being near the top, the dust cannot get to it, and the bright working part of the cylinder traversed by the packing ring is never uncovered or exposed to the direct action of the dust and heated gases. Any dust entering the cylinder from the furnace is blown out at the exhaust from the bottom. The piston is lubricated with dry plumbago powder, and in practice the cylinders are found to maintain a good working face, and to be as durable as those of steam engines; in fact it is found that a film of black-lead taking a high polish is continually being deposited upon the inner surface of the cylinder, and the cylinder has as great a tendency to diminish in diameter from this cause as it has to be worn larger by friction.

The chief peculiarity in this engine is the arrangement by which the top of the working cylinder serves as the air-pump, and is made to deliver into the furnace for expansion the reduced bulk of compressed air required for performing the work. At the top of the stroke the piston does not reach the cylinder cover, but a considerable clearance space is left between them, the capacity of which has been determined by experiment so as to give the best effect; the result arrived at is that the pressure in the furnace should never exceed 15 lbs. per square inch above the atmosphere. In the first portion of the upstroke the air contained in the air-pump is compressed to half its volume, or to a pressure of 15 lbs. per square inch, and not till then does there exist equilibrium between the air in the air-pump and that in the furnace; the delivery valve T then opens, as shown in Fig. 6, Plate 18, and during the remainder of the upstroke the air is

pumped into the furnace. At the end of the stroke the valve T closes, leaving still 15 lbs. pressure in the space above the piston; and as there is no further escape for this, it acts upon the piston during part of the downstroke, and equalises the action of the engine to such an extent that a small flywheel only is required. This is not put forward as any advantage in power, because whatever force is required in order to obtain the pressure of 15 lbs. above the piston must be deducted from that of the upstroke; it is but transferred from the lower side of the piston to be utilised above it in the subsequent expansion of the compressed air. As soon as the air above the piston has expanded down to atmospheric pressure in the downstroke, the inlet air-pump valve U opens and admits the quantity of cold air required for the next stroke of the engine. By holding open this valve by means of a small hand lever placed below it, the cold air is merely pumped through it in and out of the air-pump, none going into the furnace, and the engine is thereby stopped. In order to start the engine, in the case of those of small size a few backward turns are given to the flywheel by hand, while the top cover is off the furnace; and from the arrangement of the valves it will be seen that when the flywheel is turned the reverse way the cylinder is converted for the time into a double-acting air-pump, forcing air into the fire during both the up and the down strokes of the engine; by this process the fire after lighting can be blown up and in a few minutes be ready for work; the furnace cover is then quickly replaced, and after a few forward turns given by hand the engine starts with the pressure due to the heating of the air in the furnace. In the larger engines it would be more convenient to charge the furnace with compressed air by means of a hand pump, in order to obtain a pressure with which to start.

With regard to the best capacity of the air-pump in proportion to that of the cylinder, it is found that air engines on this principle cannot be worked advantageously at a high pressure. In one experiment the capacity of the clearance space above the piston was diminished so as to give the air a pressure of 25 lbs. above atmosphere; but with this pressure the engine was found to

work so much hotter that the heat generated by compression repeatedly set fire to the hemp packing in the glands of the piston rods; the working pressure had therefore to be reduced. If the air forced into the furnace, measured at atmospheric pressure, be equal to the cubical contents of the cylinder, or in other words if the air-pump and cylinder be identical in size, the force obtained from the expansion of the air by heat is so nearly absorbed in overcoming the resistance offered by the air during its compression in the air-pump that little or no power will be obtained from the engine. On the other hand if the air delivered by the pump, measured at atmospheric pressure, have only half the cubic capacity of the cylinder, the air will require an increase of 510° Fahr. (if taken in at 50° temperature) in order to double its volume and fill the cylinder at atmospheric pressure, the engine still giving off no power. The mean of these two extremes has therefore been taken, the capacity of the air-pump being made such that the volume of air forced intc the furnace, measured at atmospheric pressure, is three-fourths of the cubic contents of the cylinder, the cushioning space above the piston at the top of its stroke being accordingly made equal to one quarter the capacity of the cylinder.

In Fig. 11, Plate 20, is shown the indicator diagram taken from one of these engines of 3 horse power, at a time when it was doing full duty with a friction break; the engine had a cylinder of 24 inches diameter with 12 inches stroke, and at the time the diagram was taken was making 108 revolutions per minute. From this diagram it is apparent that the exhaust was not quite so free in this particular engine as it should be, the downstroke showing too much back pressure at the commencement. The diagram shown in Fig. 12 is that of the air-pump, and represents the power required for compressing the air above the piston; it was taken immediately after Fig. 11, upon the same paper, by simply turning a three-way cock which shut off the passage to the bottom of the cylinder and opened that to the air-pump. In this air-pump diagram it will be seen that the line begins from the zero point on the left of the diagram, and gradually rises with the

usual compression curve till it arrives a little beyond half stroke; during this time the delivery valve is not open, and no air is sent into the furnace. As soon as the pressure of the air in the pump begins to exceed that in the furnace, the delivery valve rises, and during the remainder of the stroke the compressed air is delivered from the pump into the furnace. When the piston arrives at the top of its stroke, the delivery valve closes; and when the piston begins to descend, there is a pressure of about 15 lbs. per square inch above it, and the body of compressed air being confined in a space of considerable capacity exerts a gradually diminishing force to about half stroke. In calculating therefore the force required to compress the air, this return pressure in the downstroke has to be deducted in the measurement of the diagram. The difference between the mean pressure in the pump, as shown in Fig. 12, and the mean driving pressure below the piston, as in Fig. 11, is 6·6 lbs. per square inch, which represents the effective driving pressure, as shown in the combined indicator diagram, Fig. 13. From the fact of the engine being single-acting with a large cylinder, the friction, as might be anticipated, is very great compared to the power; for it is found that while the indicated horse power, as shown by the combined diagram, Fig. 13, amounts to 9·76, the actual working power obtained at the friction break is only 3·30 horse power. This air engine has proved very successful for cases where a small amount of power is required, and has the advantage of working for long periods without requiring attention either for firing or for the engine, and with freedom from the risk of explosion or fire attending the use of a steam engine.

The actual temperatures of the air have now to be considered, first at its entrance to the cylinder from the furnace, and secondly upon leaving the cylinder at the exhaust after performing its work. The temperature of the air upon leaving the furnace was ascertained by one of Mr. Siemens' electrical pyrometers, which he most kindly placed at the author's disposal for the purpose of these experiments. The instrument was fixed into the curved pipe Q, Fig. 4, Plate 17, leading from the furnace to the cylinder, the pyrometer itself being

inside the pipe, about half way between the furnace and the cylinder. A more convenient mode of measuring temperatures can hardly be imagined, the indicating instrument being placed in the office many yards from the engine to be tested, and connected with it by a conducting cable; thus the observer was far removed from any annoyance or heat from the engine, and all he had to do was from time to time to send a telegraphic enquiry to Mr. Siemens' "salamander," whose post was in the hot-air pipe Q, and an answer was instantly received giving the temperature of that great heat with perfect accuracy. From the average of a series of readings it was found that the air entered the working cylinder at a temperature of 1127° Fahr., equal to the dull red heat of an ordinary open fire. The average temperature of the air as it leaves the cylinder, ascertained by a mercurial thermometer placed in the exhaust port, was found to be 466° Fahr., a temperature at which steel acquires a pale straw colour, and about 16° above the melting point of tin. It thus appears that 661° is absorbed in doing the work, and 466° or nearly 40 per cent. of the whole heat is thrown away in the exhaust.

With regard to the consumption of coal, in these engines of one horse power it is found to be about 80 lbs. for ten hours' work, or 8 lbs. per horse power per hour. It thus appears that, even with the wasteful system of discharging the highly heated exhaust air, without any means of recovering the heat and utilising it by making it warm a regenerator through which the cold air delivered into the furnace from the air-pump might be passed, these engines can yet compete successfully with small steam engines in economy of fuel; and if a regenerator were added, and every arrangement were carried out to obtain the best theoretical effect due to air expanded by heat as a motive power, these engines would equal or surpass in economy of fuel the results of the best engines worked by steam. The difficulties met with are chiefly of a practical nature, and may be ultimately overcome, as several of them have been already in the engines now at work.

No allusion has been made in this paper to engines worked by gas, by gas and air, or by steam and air; in fact only those

heated-air engines that seem to have played a characteristic part in the history of the subject have been described. When it is stated however that during the last half century upwards of 250 plans have been brought out for the application of air expanded by heat as a motive power, it will be seen how much attention the subject has received; but undoubtedly the first practical scientific application of the dynamical theory of heat is due to Mr. Siemens, whose name is so intimately and so honourably associated with the rise and progress of that great discovery of modern science. He was one of the very first who enunciated and demonstrated the conversion of heat into mechanical force, and in his regenerative steam engine a practical record remains of the strength of his convictions as to the truth of that theory at a time when it was received by only a few prominent physicists, such as Helmholz and Mayer in Germany, and Joule, Thomson, and the late Professor Rankine in this country; and it is an interesting fact, as showing the correctness of his reasoning, that Mr. Siemens' remarkable paper upon the conversion of heat into mechanical effect, though read before the Institution of Civil Engineers in 1853, just twenty years ago, is as much in accordance with modern scientific thought as if it had been written in the present year, and indeed contains nothing that new discoveries have not tended to confirm.

It now only remains to the author to acknowledge his obligations for the assistance rendered him in the preparation of this paper: to Mr. Wenham, for extensive notes and data supplied for the purpose; and to Mr. Siemens, to whom the author is indebted for much valuable information, and especially for the use of the very beautiful electrical pyrometer with which the temperatures were ascertained, and without which only a rough and scarcely approximate result could have been arrived at.

Mr. Cooke exhibited a model of Wenham's engine, and one of the engines was shown at work in the neighbourhood before and after the meeting, together with the Siemens electrical pyrometer by which the temperatures of the heated air were ascertained.

Mr. Wenham remarked that the time had fairly arrived when the soundness of the principle of using heated air as a motive power might receive some further consideration, as to the extent to which it could be practically applied and the best mode in which that could be effected; for the difficulties which had hitherto retarded the application of the principle had been chiefly of a practical nature. One of the main difficulties was the heating of the joints; if the engine now described were allowed to run for half an hour with extra work upon it, beyond what it was intended to do regularly, the great heat generated in the furnace and required by the engine to perform that work would cause the joints to start. This was a very serious matter in these engines, for it was their peculiarity that they would not bear the slightest degree of leakage; a definite measure of air was taken into the engine at each stroke, and the smallest leakage was therefore perceptible at once in a reduction of pressure; the falling of the governor then caused an increased proportion of air to pass underneath the firegrate, thereby augmenting the heat and further aggravating the evil.

With regard to the fuel used, the best kind of coal for raising steam was not found to be the best for this engine; but very inferior bituminous descriptions could be used with advantage, particularly if containing a considerable quantity of moisture. This had suggested the idea that for keeping the engine cool it would be well to inject a small quantity of water into it; but there was a difficulty in doing so, because when the engine was left standing and had got cold, the interior of the cylinder became corroded by the moisture, and it would be difficult to start the engine again. He thought however it would be well for the air to be introduced into the engine in a moist condition, or that some means should be provided for supplying moisture to it above the fire; and he understood experiments were now being made with this engine with that object in view.

For lubricating the piston, oil was first used, as the top of the cylinder did not get hot, but continued cool enough after a day's work to bear the hand on it; but though the oil remained fluid while the engine was working, it got clogged as soon as the parts became cold, and this seemed to be a fatal objection, requiring the cylinder to be carefully cleaned out every day through a lid in the top cover. Plumbago was then tried and answered extremely well, and he had never known a case of the cylinder scoring when lubricated with plumbago. The dry plumbago powder was blown into the cylinder above the piston opposite the air passage, and the rush of cold air entering the top of the cylinder rather tended to sweep the plumbago backwards; the powder gradually worked its way round the circumference of the piston, and covered the cylinder with a bright coating, which rendered it quite as durable as the cylinder of a steam engine.

Mr. E. J. C. Welch mentioned that in making experiments six years ago with Edwards' hot-air engine one of the chief difficulties he had met with was the distortion of the working parts from the engine getting too hot; the longer it worked, the hotter it became, and the working parts getting out of square caused friction enough to stop the engine. The lubrication of the piston had been a source of trouble, the packing being made simply with three ordinary rings; plumbago alone was tried first, and then a mixture of plumbago and soapstone, which was found to lubricate more effectually than plumbago alone. When the engine got too hot, leakages arose, and a very slight leakage of air was sufficient to bring the engine to a standstill; nor did there seem to be any means of supplying by an extra large air-pump sufficient air to compensate for these ordinary leakages; the door of the furnace was ground on in its seat, and every precaution taken to prevent leakage, but without success. Another difficulty had been that particles from the ashes carried over from the furnace got under the air valves and prevented them from closing completely; anything that caused the valves to stick was of course fatal to the working of the engine, and he had therefore tried an equilibrium slide-valve, instead of the flap valves, and found it worked satisfactorily. He had had an engine

made with a cylinder of only 6 inches diameter, and with a separate pump to maintain the supply of compressed air; but though carefully made, the friction in so small an engine was found to absorb all the power that could be generated.

Mr. Wenham said the smallest size made of his engine had a cylinder of 12 inches diameter, and the effective power developed by it as measured by a friction break was half a horse power. He had never experienced any trouble from ashes getting under the valves in any of the forty engines that had now been constructed and put to work; the valves came down heavily in closing, and would stamp to a fine powder any particles of ashes lodged upon the seats, nor had he ever known the engines miss a stroke and stop from this cause in consequence of any of the valves sticking partly open.

Mr. J. McFarlane Gray observed that the indicator diagram from the heated-air engine furnished an explanation of the reason why such an engine of small size, say with a cylinder of even as much as 6 inches diameter, would be prevented from working by the excessive friction. For the production of the greatest amount of power, the object in any engine was to get the full part of the indicator diagram as near the middle of the stroke as possible, the leverage of the crank being there the greatest; while near the ends of the stroke, however great the pressure upon the piston, a large percentage of the power was lost by friction. The diagram now exhibited however showed a considerable effective pressure acting upon the piston at the two ends of the stroke, but scarcely any in the middle, on account of the back pressure of the compressed air above the piston at that time being equal to the driving pressure of the heated air below the piston. Moreover it appeared from the diagram that the mean effective pressure throughout the stroke was only 6·6 lbs. per square inch, and as the engine was only single-acting instead of double-acting this was equivalent to only 3·3 lbs. average pressure in each stroke, which again was reduced to 2·3 lbs., as the friction could not be estimated at much less than 1 lb. per square inch on the piston. Considering that in a steam engine the average effective pressure in each stroke was very commonly as

much as 20 lbs. per square inch, the balance in favour of steam appeared to him to be very great.

Moreover on comparing the expansion curve of air with that of steam, when expanding heated air in the working cylinder of an engine, it was found that, starting in each case with an equal volume and pressure, the utmost additional theoretical effect that could be obtained by the expansion of the air to infinity would be only 2·45 times the work done by the air acting without expansion; whereas with steam indefinitely expanded the theoretical additional effect would be about 9 times the work of full pressure, showing an advantage of more than three to one in the expansion of steam as compared with that of air. This great difference in favour of steam was frequently lost sight of he thought in considering the relative capabilities of steam and caloric engines, and appeared to him to recommend steam as the most peculiarly advantageous medium for transforming heat into work.

Mr. Wenham mentioned that some experiments he had made in expanding the air within the cylinder of the engine had not been productive of any beneficial results in practice, because the initial pressure of the air was so low that the benefit of the expansion was not appreciable; and to carry out expansion to such an extent as materially to increase the power of the engine would have involved so great an increase in size of cylinder that it had not been attempted.

Mr. E. A. Cowper had seen Ericsson's first caloric engine in 1834, as well as his second one of 24 horse power made shortly afterwards, and many others by different makers; and although Ericsson's 24 horse power engine undoubtedly worked pretty fairly at times, and with a small fire, it did not keep in order long, and on the whole was very unsatisfactory, though much money was spent on it by Mr. John Braithwaite, with whom he himself was then articled. It was a very complete pair of engines, with cranks at right angles, and a large and a small cylinder to each engine. The engine worked a horizontal double-acting pump, 30 inches diameter and 3 feet stroke, and drove the water over the top of a standpipe some 20 feet high; and in order

to give it more work to do, a loaded safety valve was added at the top, and the pump had to drive the water out under this valve. The theory of the caloric engine was to heat a certain quantity of air, and, after a certain amount of work had been obtained from its expansion, to absorb the remainder of the heat from it and utilise this for heating another charge of air; and both Stirling's and Ericsson's engines had been constructed with the idea of recovering and using over again the heat still left in the air after doing work in the engine. Several caloric engines that had been designed from time to time had not been made to save the heat left in the air after use, and this would seem to be a source of great loss; possibly some arrangement could be added to the engine described in the paper to do something in this way, so as to reduce the very heavy consumption of fuel that had been named, though of course it was not wise to burden an engine so small as only 2 horse power with much complication. He believed the difficulties increased greatly when caloric engines were made at all equal in power to ordinary sized steam engines, and these practical considerations had always deterred him from attempting to do anything in the way of making a caloric engine. He should like to mention that in some marine steam engines 1 indicated horse power had now been obtained with a consumption of only 1·3 lbs. of coal per hour, by expansive action in two cylinders carried to a high degree; and although the theoretical minimum consumption could never be reached in practice, he hoped the actual consumption might yet be reduced still further than it had at present been.

The PRESIDENT enquired what sizes had been made of the engine described in the paper, and what was the smallest size that was considered advisable.

Mr. WENHAM replied that the engines had only been made of three sizes, with 12, 15, and 24 inch cylinders; several engines of the largest size were now at work, and some of them had been in use as long as five years. The manufacture of the smallest size, with 12 inch cylinder, which had been of half a horse power, had now been quite abandoned, because it cost nearly as much to make

an engine of that size as the one horse power engine with 15 inch cylinder shown in the drawings; and as the size increased he had no doubt the engines would prove more economical and effective. For a large power it might be better to have two cylinders of half size, instead of a single large one. The main point was to keep down the heat from the furnace, so as avoid risk of injuring the joints, and with this view the later engines had been made with a larger area of firegrate and a smaller combustion-chamber. Refuse slack of Welsh coal had been burnt in these engines until nothing was left but a cake of slag.

Mr. W. E. Newton enquired what was the power of one of these engines with 24 inch cylinder; and whether any further information could be given relative to the consumption of coal per horse power.

Mr. Wenham replied that the 24 inch cylinder engine was of about 4 horse power. He had not obtained any further particulars relative to the consumption of fuel than those given in the paper, a one horse power engine working for ten hours on a consumption of 80 lbs. of coal, which was equivalent to 8 lbs. per horse power per hour. There was a slight difference in the working of the engine in summer and in winter, rather more power being developed in cold weather on account of the greater density of the air taken in.

Mr. C. E. Amos remembered that at one of the meetings of the Royal Agricultural Society one of Ericsson's engines had been exhibited by Messrs. Ransomes and Sims, and the experiments then made with it showed that the amount of power given out was remarkably small for so large an engine, while the consumption of fuel was very large, amounting to about 18 lbs. of coal per horse power per hour; he did not know what became of that engine afterwards. Some years subsequently another heated-air engine had been exhibited at Vichy in France; and application having been made to himself to construct a larger engine on the same plan, he had had the original engine brought over to this country for the purpose of ascertaining its actual performance, and had found that, though developing as much as 8 horse power, it gave out an effective result of only $1\frac{1}{4}$ horse power at the flywheel, the remaining $6\frac{3}{4}$ horse power being absorbed by the engine. Such an engine if applied to

locomotive purposes, as had been contemplated, would have required a whole train to carry the cylinders necessary for producing the requisite power; and he had accordingly declined to have anything further to do with it. With respect to the hot-air engine described in the paper, it was to be observed that it had the advantage of being perfectly safe from explosion or from any danger of fire, and might be handy for purposes where not much power was wanted, such as for a pumping engine on a country estate; he believed however that great improvements would have to be effected before any hot-air engine could be brought into comparison with a steam engine for general use.

The President said that many years ago he had given much attention to the question of obtaining from heat a larger proportion of mechanical effect than had previously been realised. With regard to the best medium to be employed for the purpose, although on theoretical grounds this was immaterial so long as no heat was thrown away, there were many important considerations in favour of steam, which had a higher rate of expansion by heat than air, and did not involve the employment of an air-pump for producing a supply under pressure. By the application of the regenerative principle he had obtained in small steam engines satisfactory results upon the whole; fifteen or sixteen engines altogether had been made on that plan, of from 5 to 10 horse power, and had worked for a series of years with very fair results. One of them had been put to work in Paris, and had been examined by Gen. Morin and M. Tresca, and in a whole day's working the consumption of coal had been found to be 1·67 kilos. or 3·68 lbs. per break horse power per hour. But on attempting to carry out the same plan in engines of larger size, of 20 horse power or more, difficulties had arisen in every direction, which had compelled him to relinquish the endeavour. One difficulty had been that mentioned in the paper with regard to the joints; and he had found that the best joint to resist a high heat was made by turning a number of concentric grooves in the faces of the flanges, and filling them with a cement composed of fine dust of cast iron mixed with white and red lead previously

mixed up with linseed oil, and worked into a very stiff cement that set as hard as iron when exposed to heat; by that means he had succeeded in making tight joints. But what had discouraged him at that time was the result he had arrived at in preparing a paper* to which reference had been made, "On the conversion of heat into mechanical effect." In considering what would give a proper conception of a really perfect engine, he came to the conclusion that if steam were generated at such a pressure as to occupy only the same bulk as the water itself, and were then expanded down until it was all condensed through expansion, the utmost effect theoretically possible would thereby be obtained, because the whole of the heat would have been converted into mechanical effect. In the accompanying diagram of a portion of the dynamical expansion curve of steam, the shaded rectangle showed the utmost power that could be obtained in a condensing engine with perfect vacuum using steam without expansion, and the result was found to be that wherever this rectangle was taken its area amounted to only 1-10th of the area of the curve expressing the power due to the ultimate expansion of the same steam; but a good high-pressure expansive engine using steam of four or five atmospheres total pressure, cutting off at about one tenth of the stroke and working down to a good vacuum, realised a very

* (See Proceedings of the Institution of Civil Engineers 1852-53 page 571). In the Steam expansion curve shown in Fig. 15, Plate 21, the horizontal scale gives the volumes of steam compared with the volume of the water from which it is produced; this is the correct dynamical expansion curve of saturated steam allowing for the loss of the heat that is converted into mechanical effect when the steam is expanded behind a working piston; the shaded area, or any other rectangle drawn to the curve, represents the power obtained from a condensing engine with perfect vacuum but without expansion. In the Air expansion curve shown in Fig. 14, Plate 20, the horizontal scale gives the volumes of air compared with the volume of an equal weight of water; the dotted curve is the hyperbolic expansion curve of constant heat, representing Marriotte's law that the pressure and volume are inversely proportionate to each other; and the full curve represents the actual rate of expansion, showing the reduction of temperature during expansion, and the consequent contraction of volume; this curve is in accordance with the observed fact that, when air at any pressure and at the temperature of 32° Fahr. is compressed to double its original pressure, its temperature is raised 70° Fahr.

considerable proportion, something like one fourth or one fifth of the theoretical maximum which could ever be obtained. The theoretical minimum consumption of fuel in a perfect steam engine he had calculated would be (taking 14000 as the total units of heat developed by the complete combustion of 1 lb. of carbon)

$$\frac{33000 \text{ ft.-lbs.} \times 60 \text{ mins.}}{14000 \text{ units heat} \times 772 \text{ ft.-lbs.}} = 0{\cdot}2 \text{ lb.}$$

or one fifth of a pound of carbon per horse power per hour; or one fourth of a pound of coal, taking into account impurities.

In the case of the air engine, it was apparent that both Stirling and Ericsson had over-estimated the real value of the regenerator under a misconception of its true action; they had imagined that it was possible to absorb and give back the whole of the heat originally put into the air, with the exception only of accidental losses, and had overlooked the fact that a portion of the heat became entirely used up by being changed into mechanical effect; both their engines had accordingly been deficient in heating power, and had failed to give permanently satisfactory results. Even supposing perfect reabsorption of heat from the exhaust air, theoretical considerations showed that an air engine was necessarily very imperfect as a means of developing power from heat; because although a volume of highly compressed and highly heated air, if expanded down to atmospheric pressure and discharged at no higher temperature than that of the external atmosphere, would yield the full result for the heat absorbed in expansion, yet an equal weight of air would then have to be taken up again and compressed to the original pressure, thereby generating a great amount of heat, which would all be wasted because it was generated in the air before its expansion by heat took place and when it should occupy the least volume, the power of the engine being dependent upon the increase of volume. In the best air engines therefore, even supposing perfect absorption of the escaping heat, it would not be possible to realise anything like so much as one fourth or one fifth of the theoretical maximum of mechanical effect due to the heat put into the air. Another drawback was that in most air engines, and particularly in Stirling's, owing to the low conducting power of air

and insufficient amount of heating surface, the cylinder or vessel in which the air was heated by the fire was found to get fully red-hot, so that the products of combustion reached the chimney at that elevated temperature. This source of loss was obviated in the engine described in the present paper, by causing the products of combustion to pass through the working cylinder, the air being heated by direct contact with them; and if the expansion in the cylinder could be carried far enough, no doubt the whole of the heat in the products of combustion might in this case be utilised; but it was clearly impossible to carry expansive action very far in this engine, owing to its low working pressure, and moreover the working of the air-pump constituted a very heavy loss of useful effect. The loss of sensible heat escaping at the exhaust might be remedied by the application of a regenerator; but this could not be done except at a sacrifice of the simplicity of construction which appeared to him to constitute the chief recommendation of the engine. It was impracticable he believed to carry out the principle of the hot-air engine on a scale sufficient to give any large amount of power; but a question of much practical importance was to produce a safe engine of small power, which could be put up anywhere, in any room, because requiring no boiler, and therefore necessitating no increased rate of insurance against fire. This object had been already accomplished by various constructions of gas engines, and was also effected by the hot-air engine now described, which he hoped would be so far perfected in its details as to give an effective power of as much as 4 or 5 horse power; and even though the consumption of coal were not reduced below 8 lbs. per horse power per hour, there were no doubt many cases in which such a source of motive power could be advantageously employed.

He moved a vote of thanks, which was passed, to Mr. Cooke for his paper, and also to Mr. Wenham for the additional information he had kindly given.

The President proposed a special vote of thanks, which was passed, to the President and Council of the Institution of Civil Engineers, for their great kindness in granting the use of the rooms of the Institution for the occasion of the present Meeting.

Mr. Hawksley, the President of the Institution of Civil Engineers, acknowledged the vote of thanks.

The Meeting then terminated.

CORNWALL MINING DISTRICT.

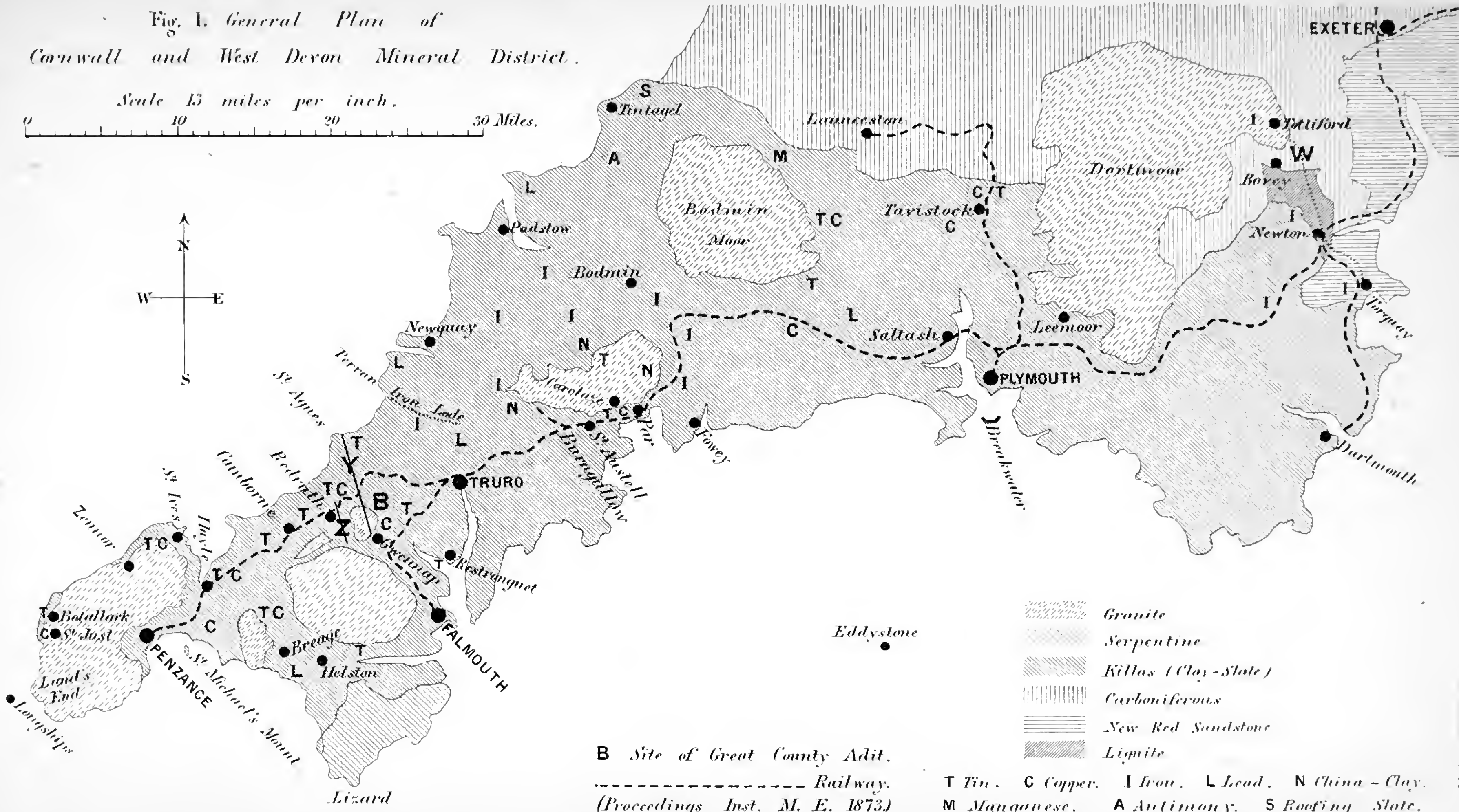
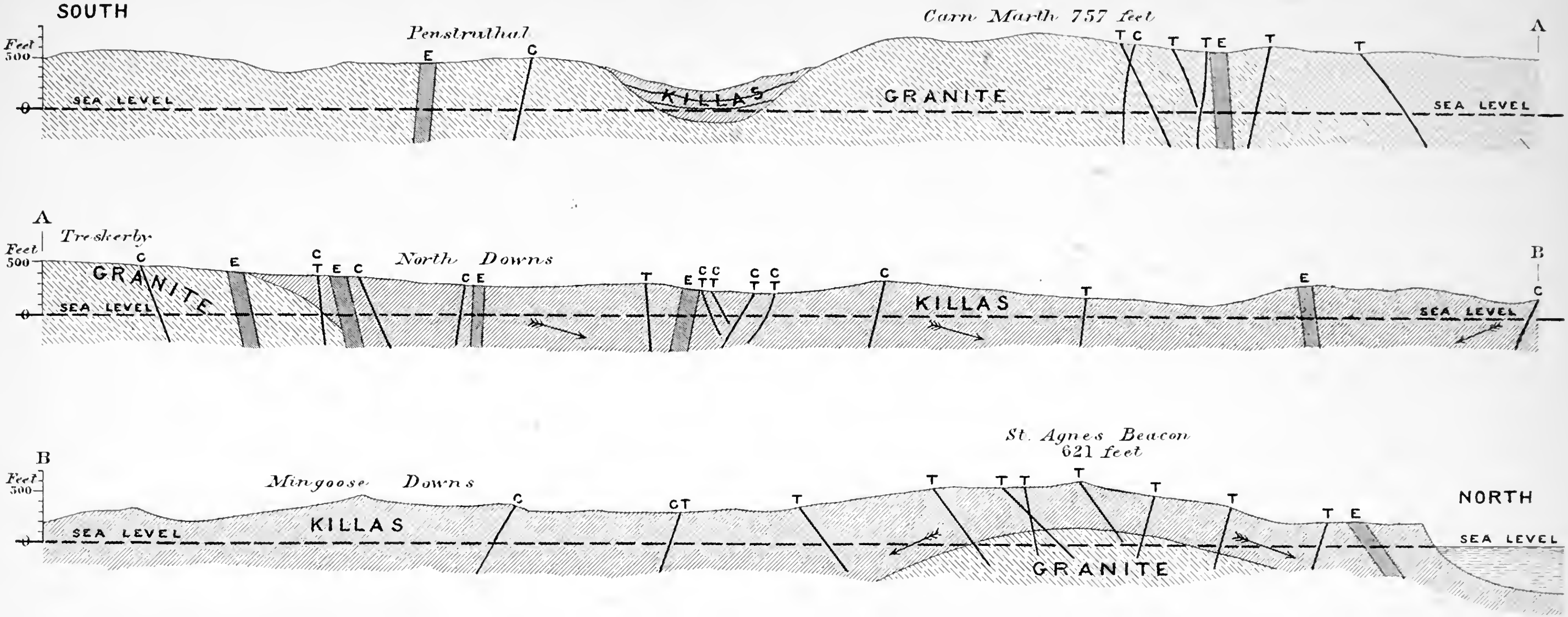


Fig. 1. General Plan of Cornwall and West Devon Mineral District.

Plate 22.

CORNWALL MINING DISTRICT.

Fig. 2. *Geological Section from South to North through St. Agnes Beacon and Carn Marth, on line Y in Fig. 1.*



The Section is continuous at the lines A-A and B-B. The arrows indicate the general dip of the slaty rocks.

Granite. E *Elvan courses (quartziferous porphyries)* T *Lodes mainly of Tin.* C *Lodes mainly of Copper.*

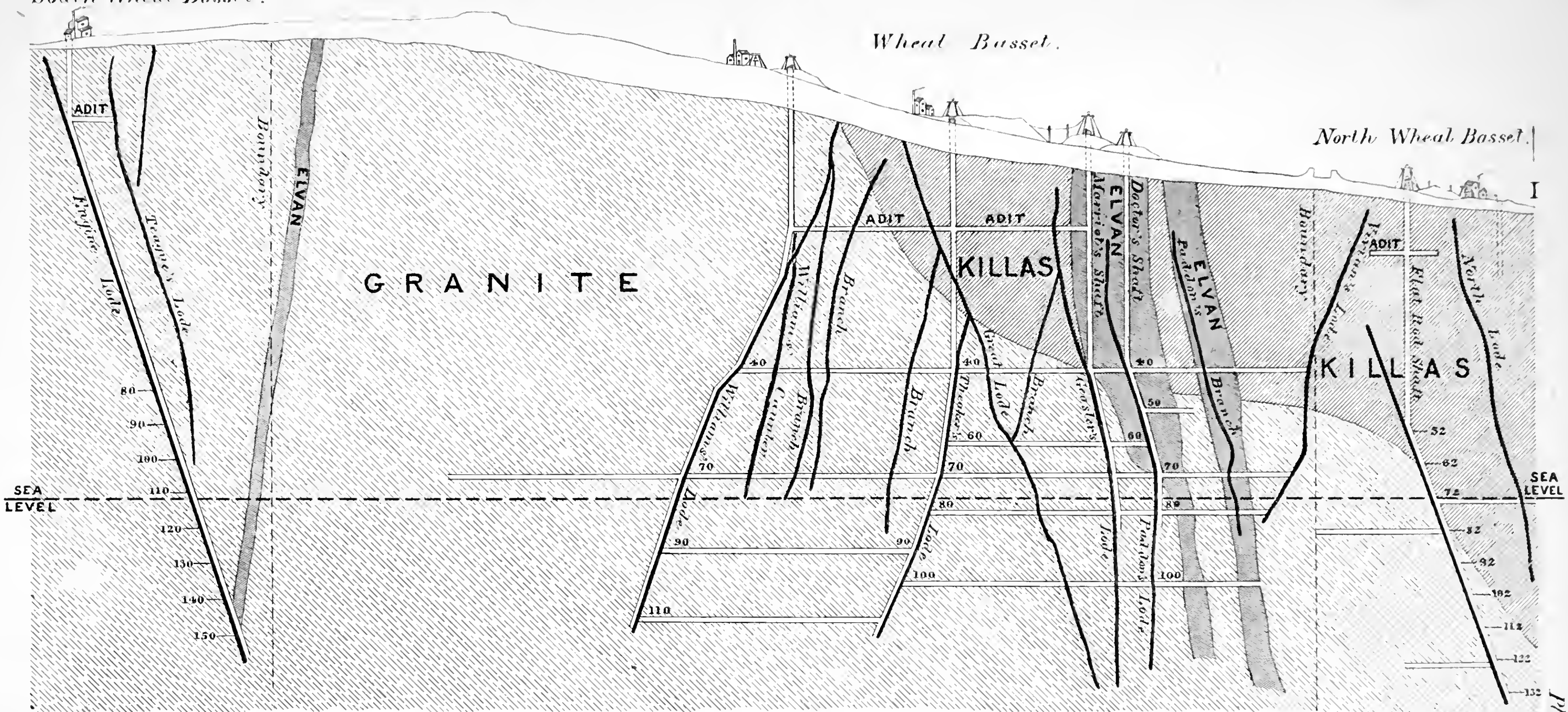
Killas (clay-slate.) *Scale $2\frac{1}{2}$ inches per mile, both horizontal and vertical.*

(Proceedings Inst. M. E. 1873.)

0 1 2 *Miles.*

Plate 23.

Fig. 3. Section from South to North through Carn Brea Hill and adjacent Mines, on line Z in Fig. 1.

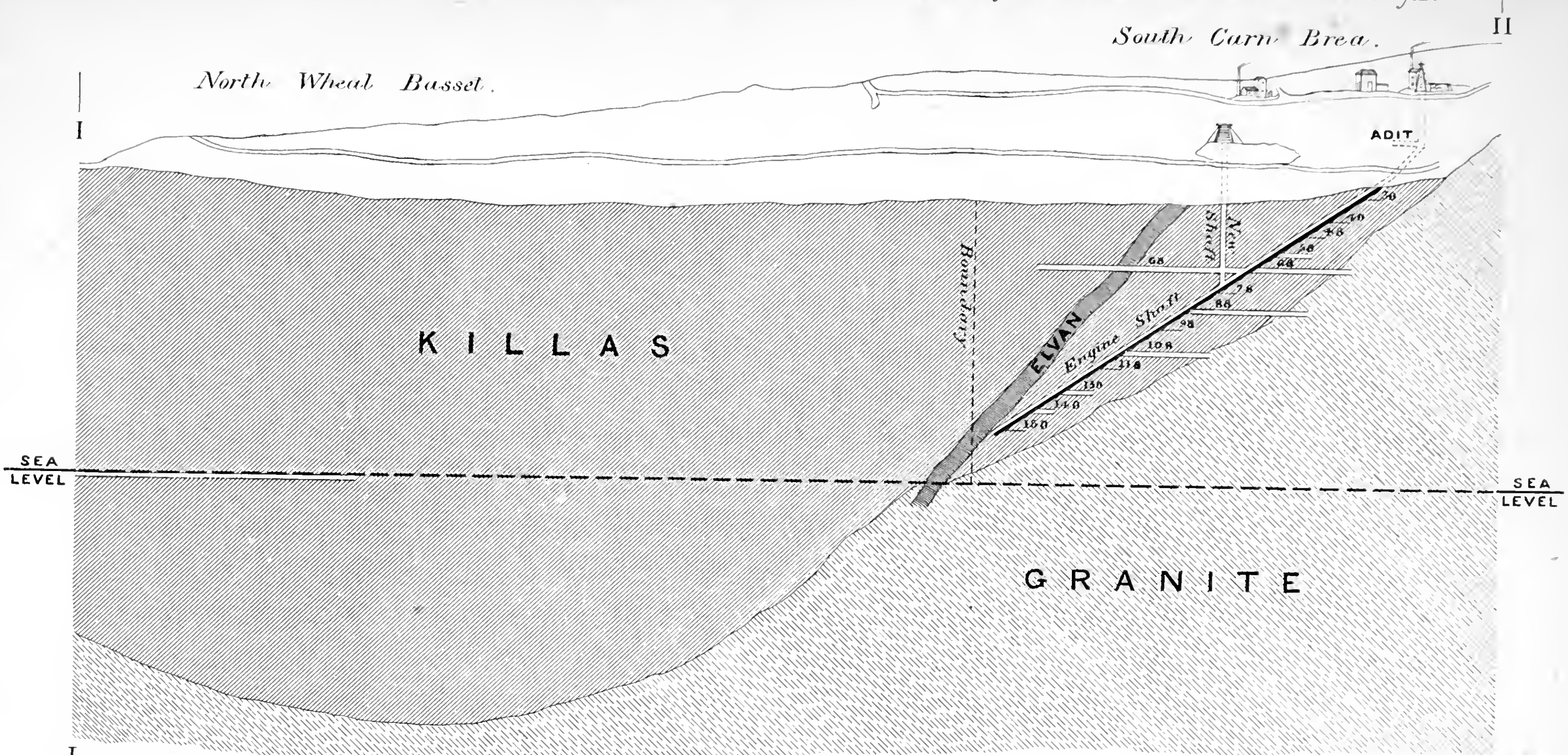


(Proceedings Inst. M. E. 1873.) The Lodes are shown black. The Elvan courses are shown dark-shaded. Vertical Scale same as horizontal. The Section is continuous in the five Plates 24–28.

Scale $\begin{cases} \text{60 fathoms per inch} \\ 14\frac{2}{3} \text{ inches per mile} \end{cases}$ 0 50 100 150 200 Fathoms. 0 1/8 1/4 Mile.

CORNWALL MINING DISTRICT.

Fig. 3 (continued). Section from South to North through Carn Brea Hill and adjacent Mines, on line Z in Fig. 1.



(Proceedings Inst. M.E. 1873.) The Lodes are shown black. The Elvan courses are shown dark-shaded. Vertical Scale same as horizontal. The Section is continuous in the five Plates 24-28.

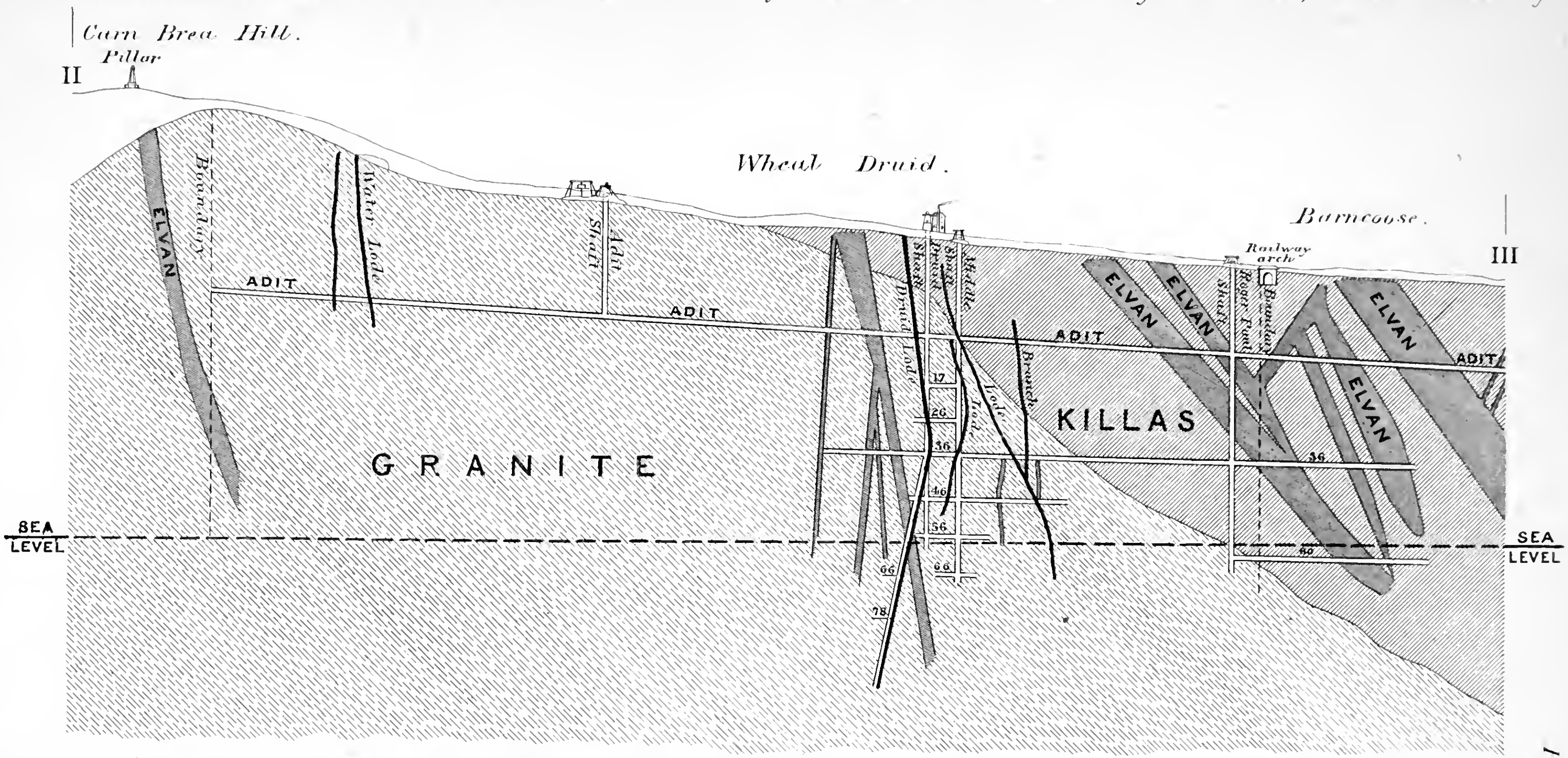
Scale { 60 fathoms per inch / $14\frac{2}{3}$ inches per mile — 0, 50, 100, 150, 200 Fathoms. 0, 1/8, 1/4 Mile.

Plate 25.

CORNWALL MINING DISTRICT.

Plate 26.

Fig. 3 *(continued)*. *Section from South to North through Carn Brea Hill and adjacent Mines, on line Z in Fig. 1.*



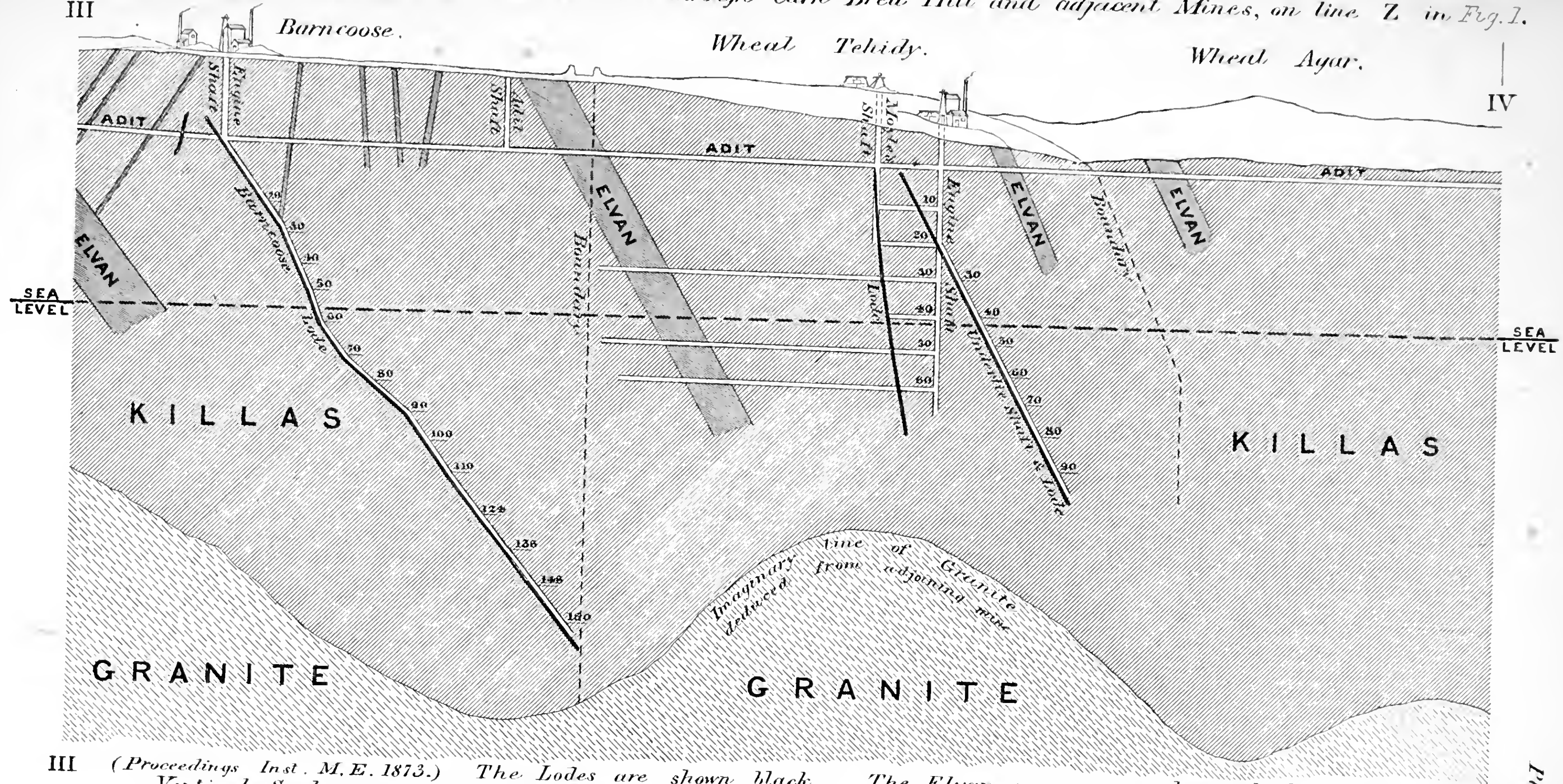
(Proceedings Inst. M. E. 1873.) The Lodes are shown black. The Elvan courses are shown dark-shaded. Vertical Scale same as horizontal. The Section is continuous in the five Plates 24–28.

Scale {60 *fathoms per inch*, $14\frac{2}{3}$ *inches per mile*} 0 50 100 150 200 *Fathoms.* 0 1/8 1/4 *Mile.*

Plate 26.

CORNWALL MINING DISTRICT.

Fig. 3 (continued). Section from South to North through Carn Brea Hill and adjacent Mines, on line Z in Fig. 1. Plate 27.



III (Proceedings Inst. M.E. 1873.) The Lodes are shown black. The Elvan courses are shown dark-shaded.
Vertical Scale same as horizontal. The Section is continuous in the five Plates 24–28. IV

Scale { 60 fathoms per inch; $14\frac{2}{3}$ inches per mile

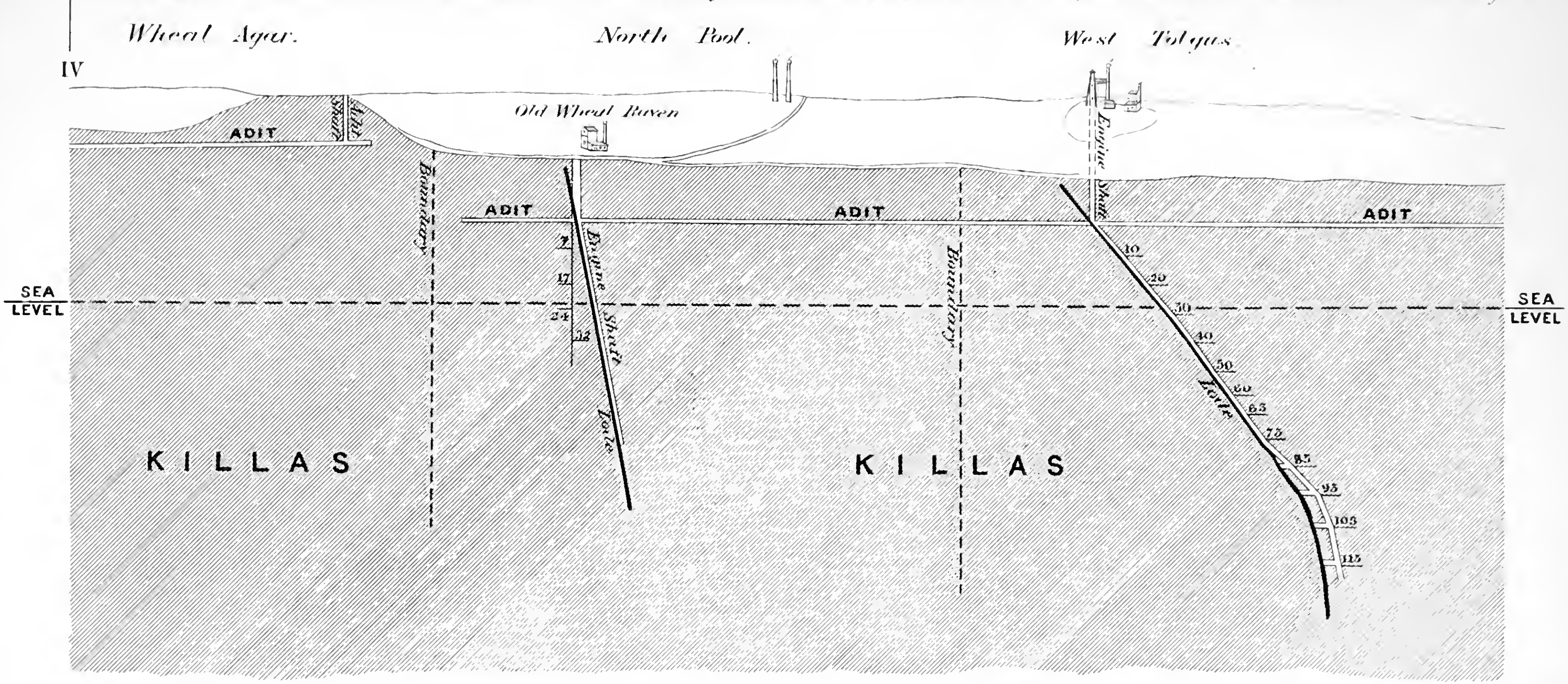
0 50 100 150 200 Fathoms.

0 1/8 1/4 Mile.

Plate 27.

CORNWALL MINING DISTRICT. Plate 28.

Fig. 3. (continued). Section from South to North through Carn Brea Hill and adjacent Mines, on line Z in Fig. 1.



(Proceedings Inst. M. E. 1873.) The Lodes are shown black.

Vertical Scale same as horizontal. The Section is continuous in the five Plates 24–28.

Scale { 60 fathoms per inch 0 50 100 150 200 Fathoms.
{ $14\frac{2}{3}$ inches per mile 0 1/8 1/4 Mile.

Plate 28.

CORNWALL MINING DISTRICT.

Fig. 4. *Plan of Lodes and Cross-courses in Wheal Seton and adjoining mines.*

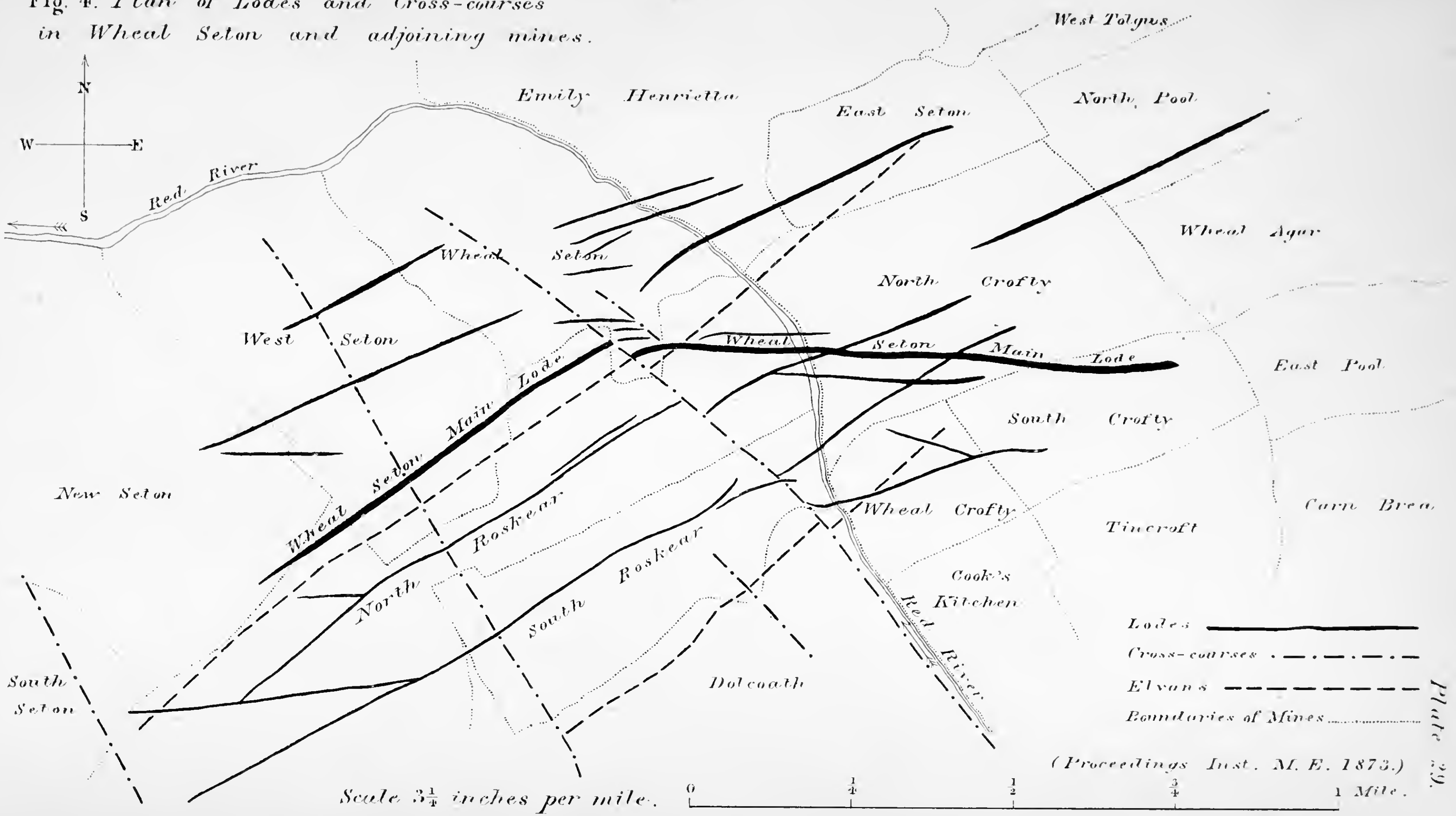
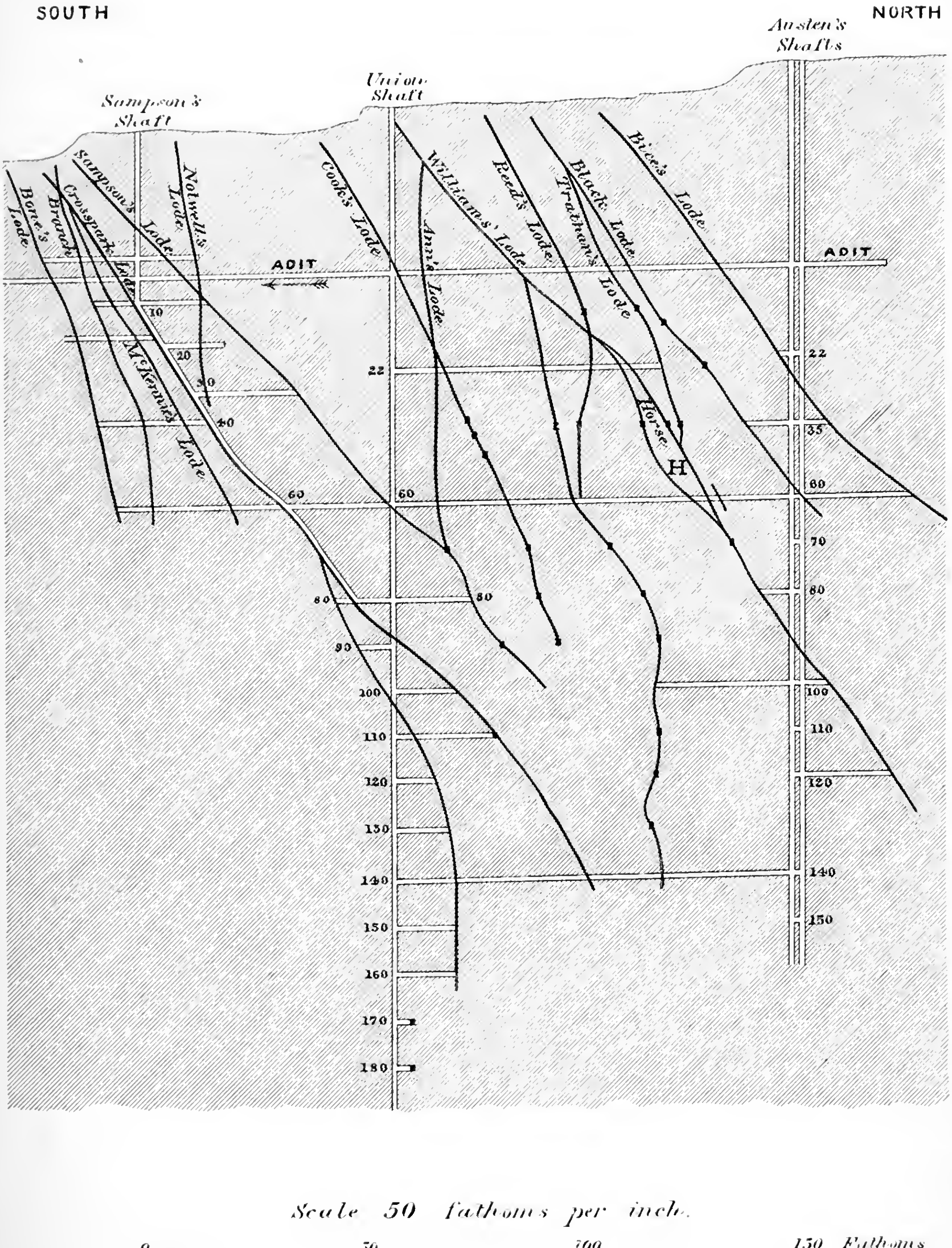


Plate 29.

CORNWALL MINING DISTRICT. *Plate 30.*

Fig. 5. *Transverse Section*

showing the Lodes in Fowey Consols Copper Mine.

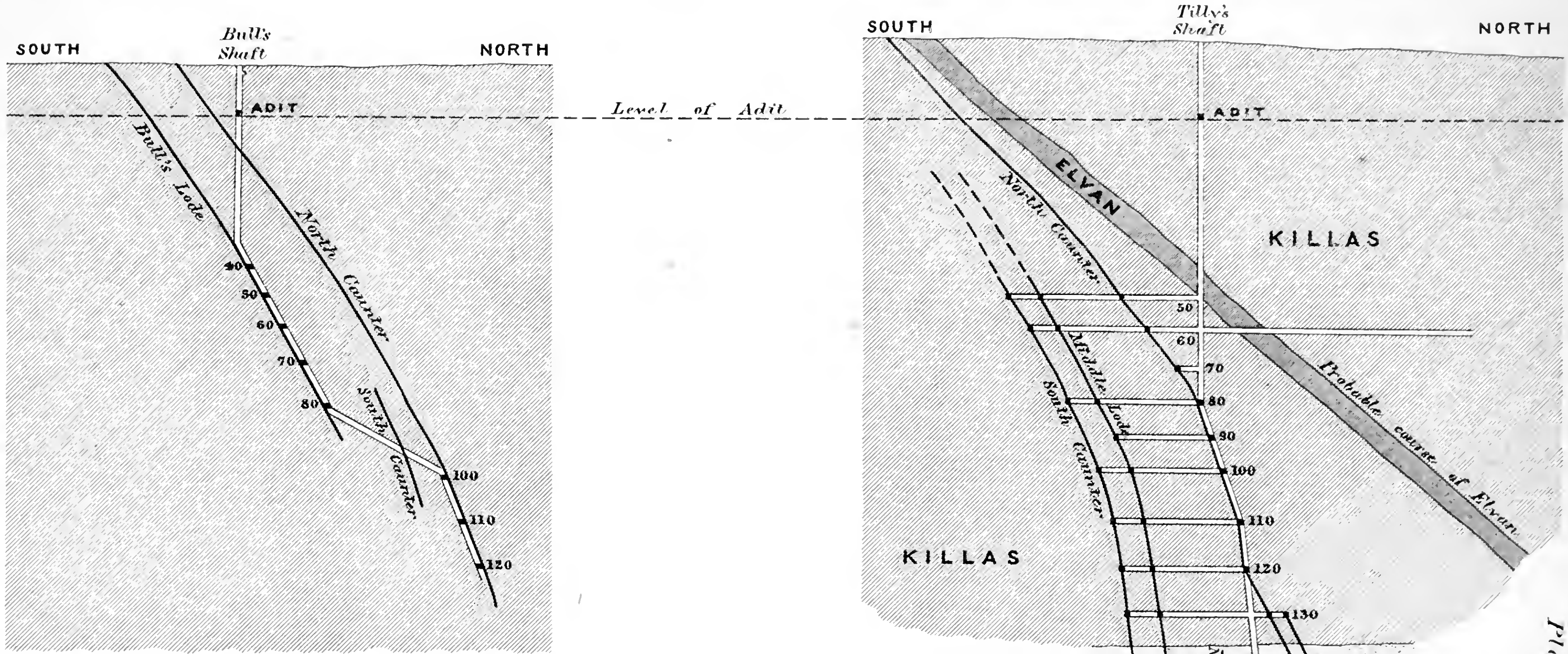


(*Proceedings Inst. M. E. 1873.*)

CORNWALL MINING DISTRICT.

Transverse Sections of same Copper and Tin Lodes at Bull's Shaft and Tilly's Shaft, Wheal Seton.

Fig. 6. *Transverse Section at Bull's Shaft.* Fig. 7. *Transverse Section at Tilly's Shaft.*



(Proceedings Inst. M. E. 1873.) Scale 50 fathoms per inch.

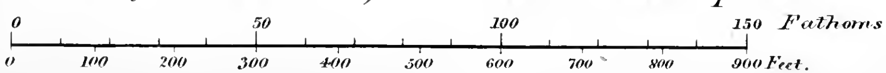
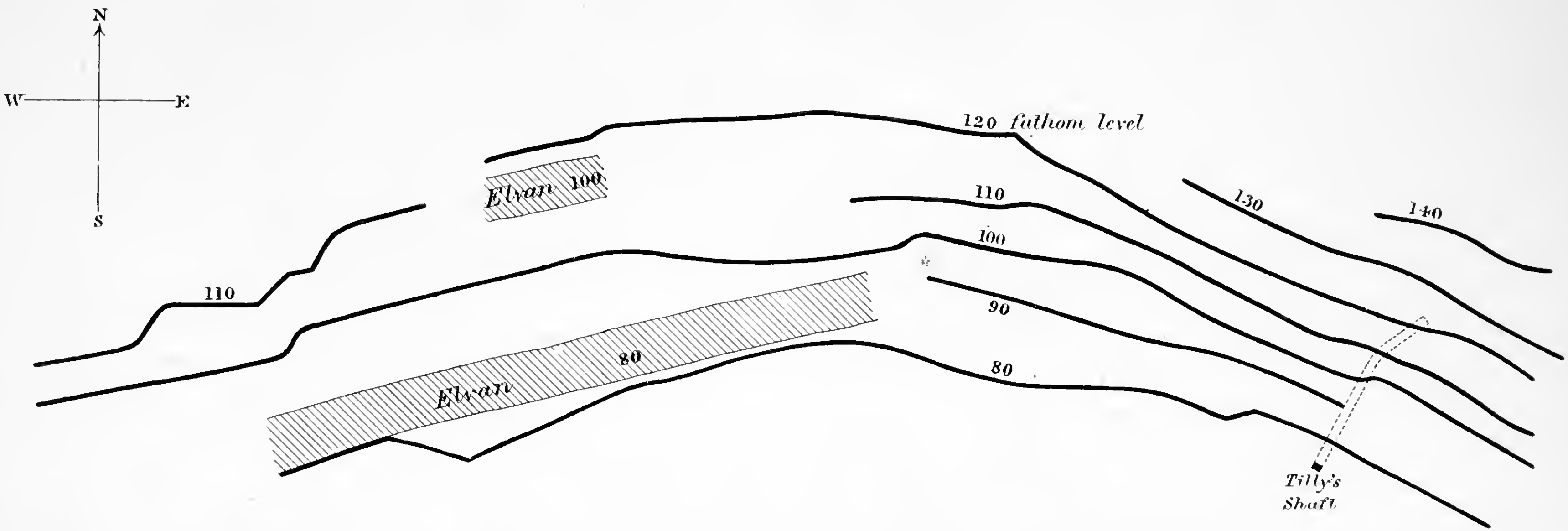


Plate 31.

CORNWALL MINING DISTRICT.

Fig. 8. *Plan of Main Lode in Wheal Seton at different Levels, showing change of bearing and underlie.*



(Proceedings Inst. M. E. 1873.) *The figures denote the successive levels at which the plan is taken.*

Scale 25 fathoms per inch.

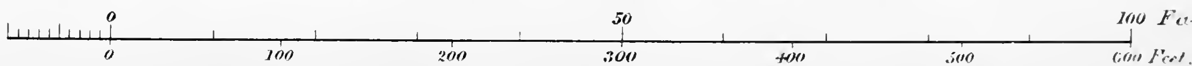
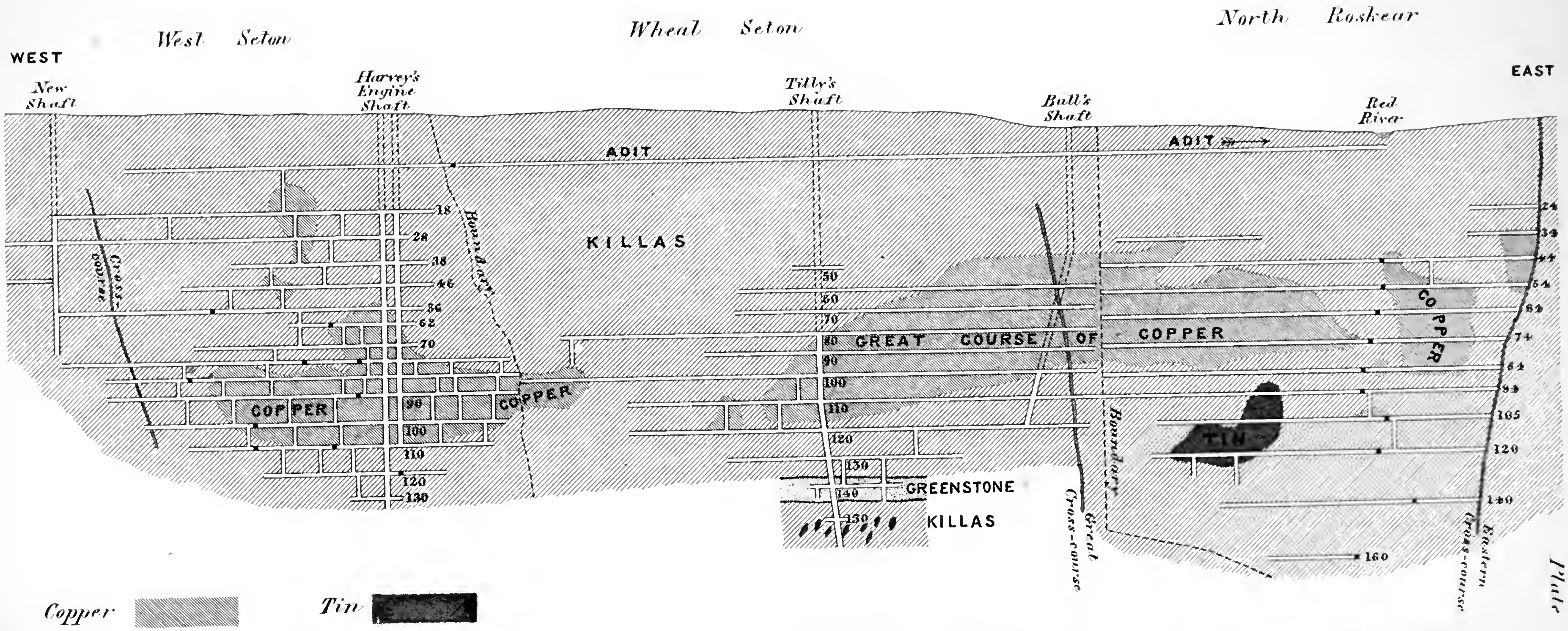


Plate 32.

CORNWALL MINING DISTRICT.

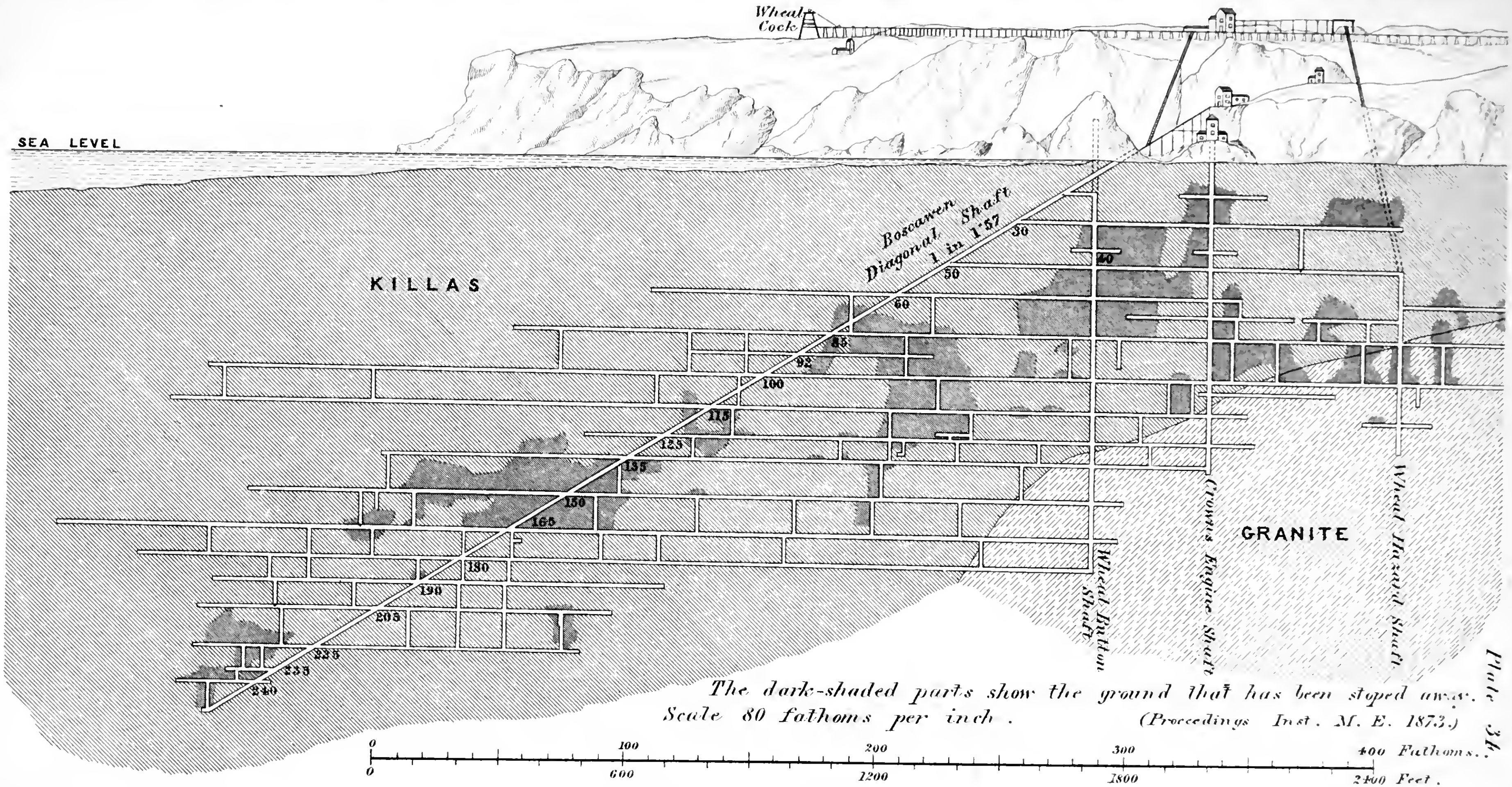
Fig. 9. *Longitudinal Section of upper portion of Workings on Wheal Seton Main Lode.*



(Proceedings Inst. M. E. 1873.) *Scale 80 fathoms per inch.*

CORNWALL MINING DISTRICT.

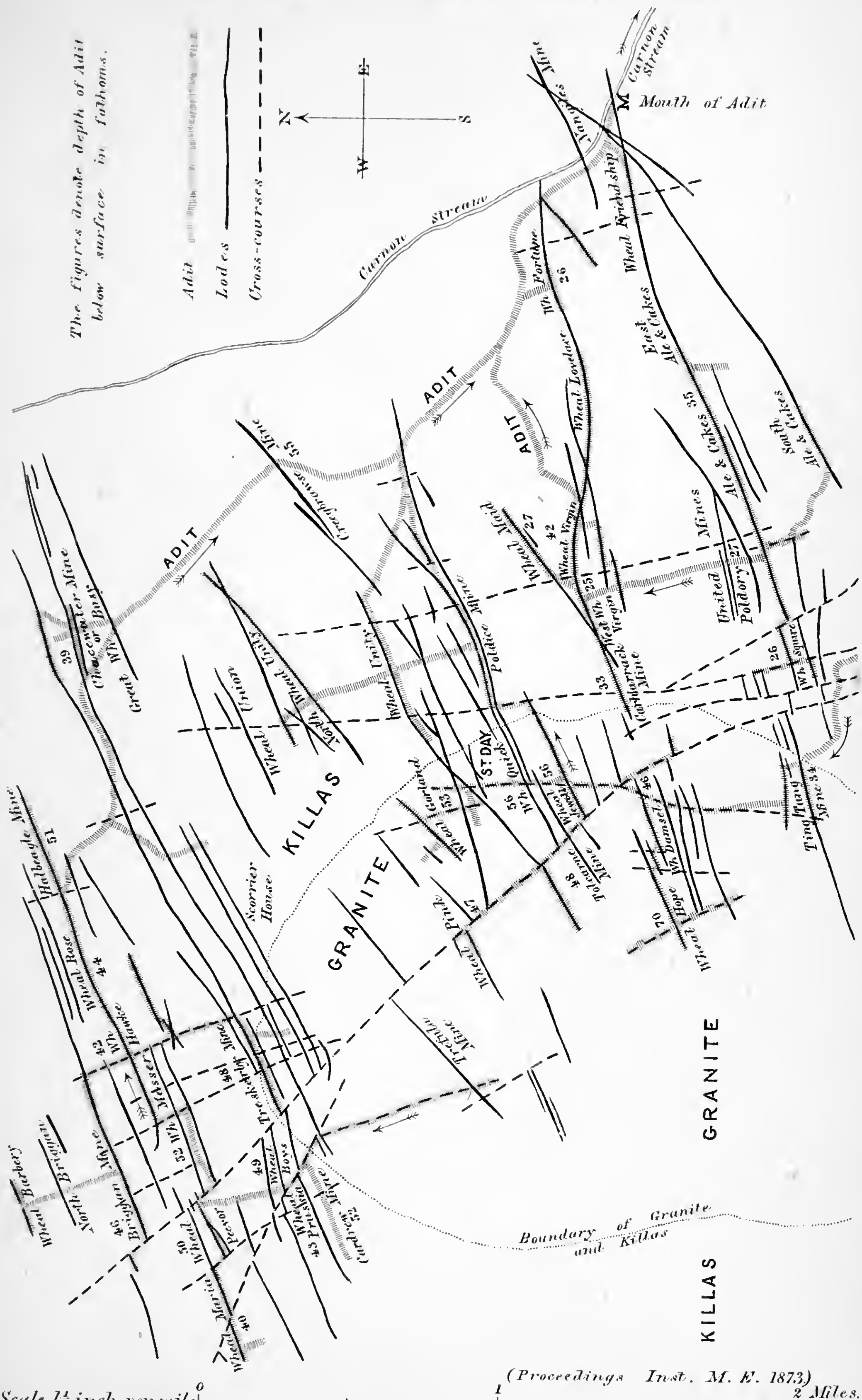
Fig. 10. *Longitudinal Section of Workings on Crowns Lode, Botallack Mine, showing Inclined Shaft.*



The dark-shaded parts show the ground that has been stoped away.
Scale 80 fathoms per inch.
(Proceedings Inst. M. E. 1873.)

Plate 34.

Fig. 11. *Plan of Great County Adit.*

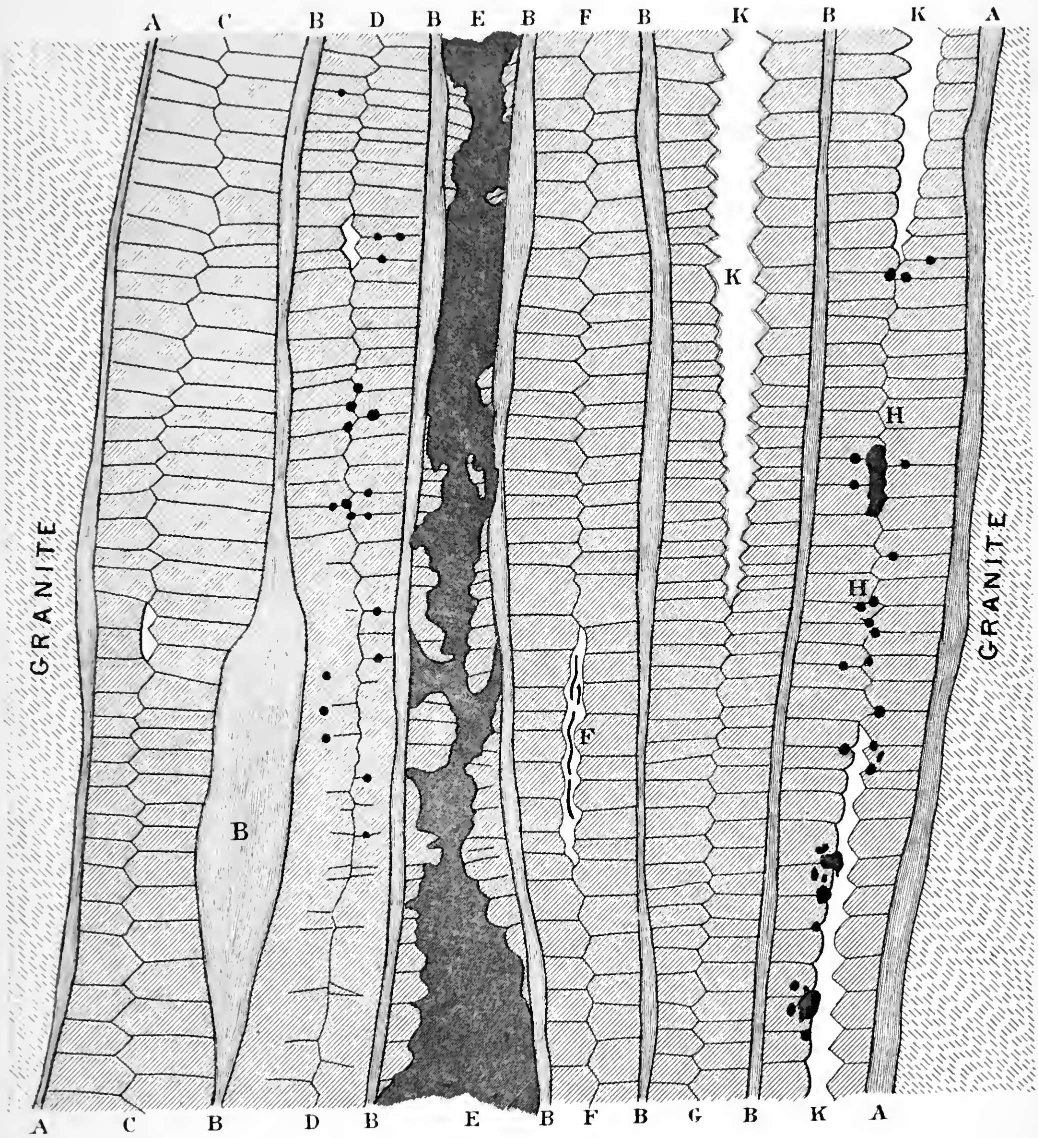


Scale 1½ inch per mile 0 1 2 Miles.

(Proceedings Inst. M. E. 1873.)

CORNWALL MINING DISTRICT. *Plate 36.*

Fig. 12. *Section of Lode in Granite at Carn Marth, showing "combed" structure.*



A A *walls of lode*

B B *clay partings*

C *quartz and purple fluor*

D *quartz with a little yellow copper ore*

E *quartz with large deposit of copper ore represented by the dark shade.*

F *quartz and purple fluor*

G *quartz*

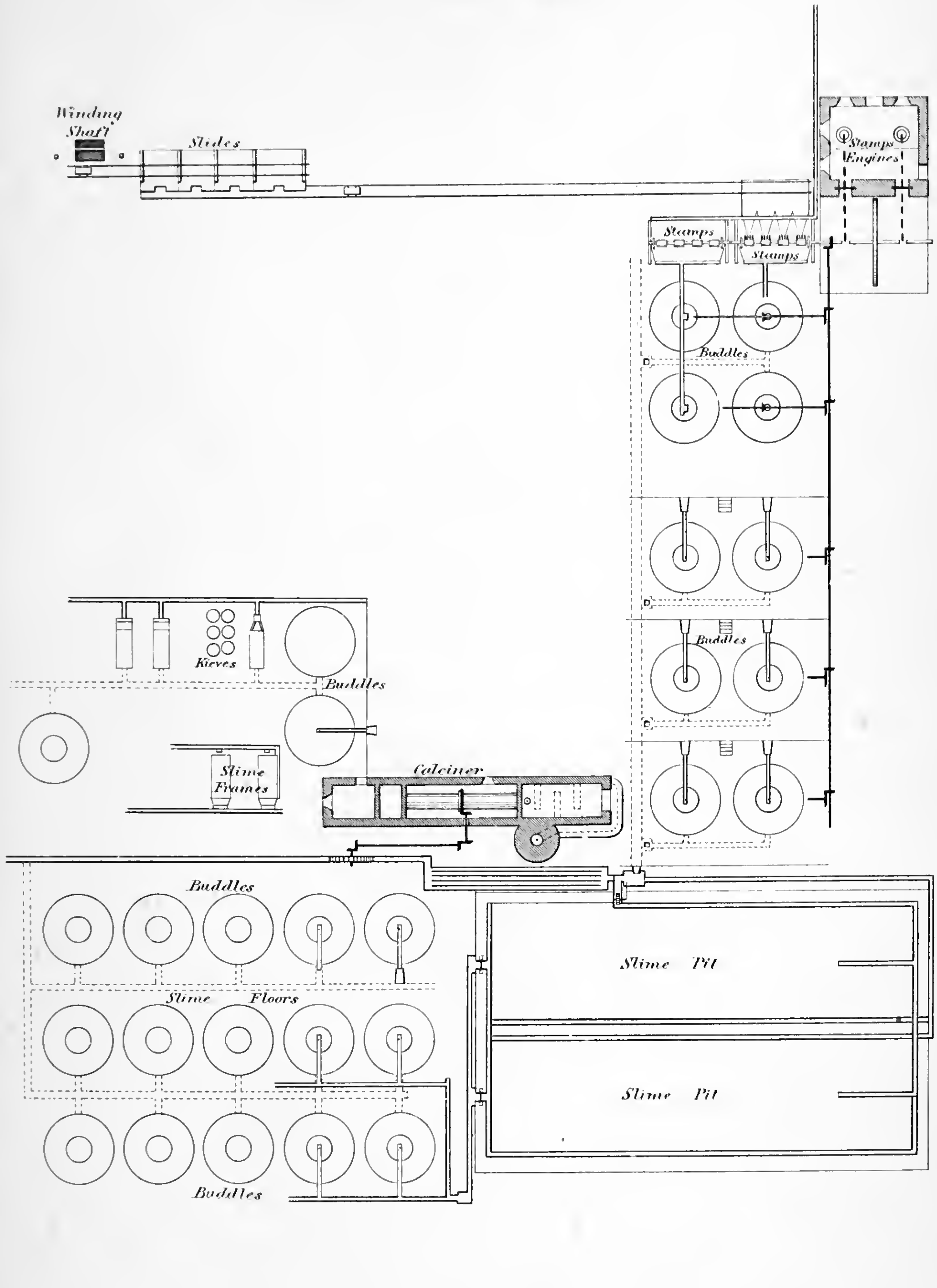
H *quartz with a little copper ore*

K K *vughs (cavities)*

The black dots and patches represent spots and bunches of copper ore.

(Proceedings Inst. M. E. 1873.) *Scale 1/6th*

Fig: 1. *Plan of Dressing Floors for a Tin Mine.*



(Proceedings Inst. M. E. 1873.)

Scale 1/700th

0 50 100 150 200 Feet.

ORE DRESSING MACHINERY.

Ordinary Stamps.

Fig. 2. *Front Elevation.*

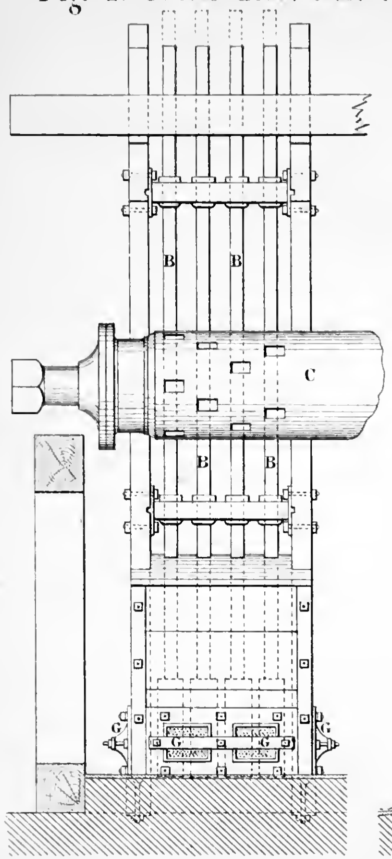
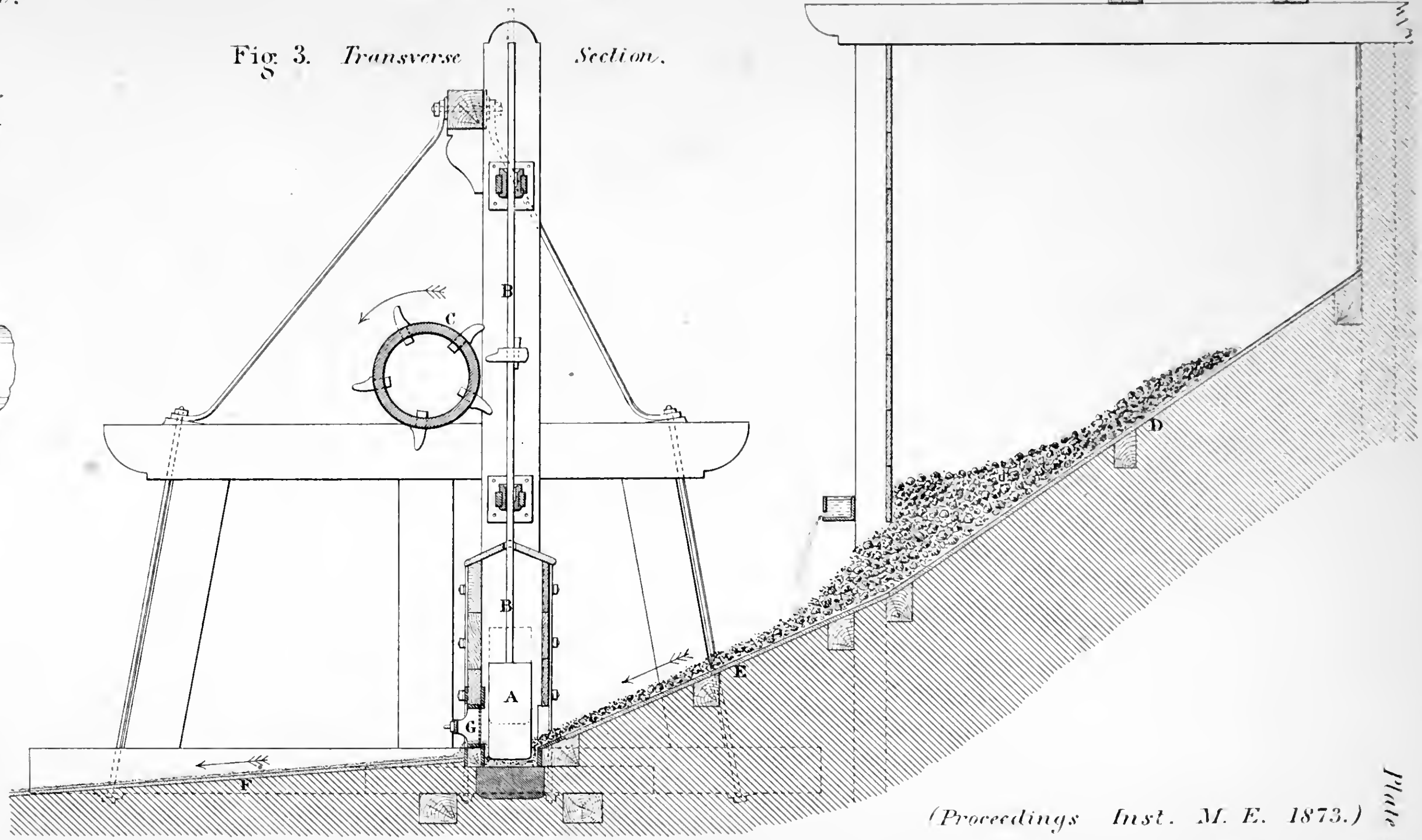


Fig. 3. *Transverse Section.*



Scale 1/60 th

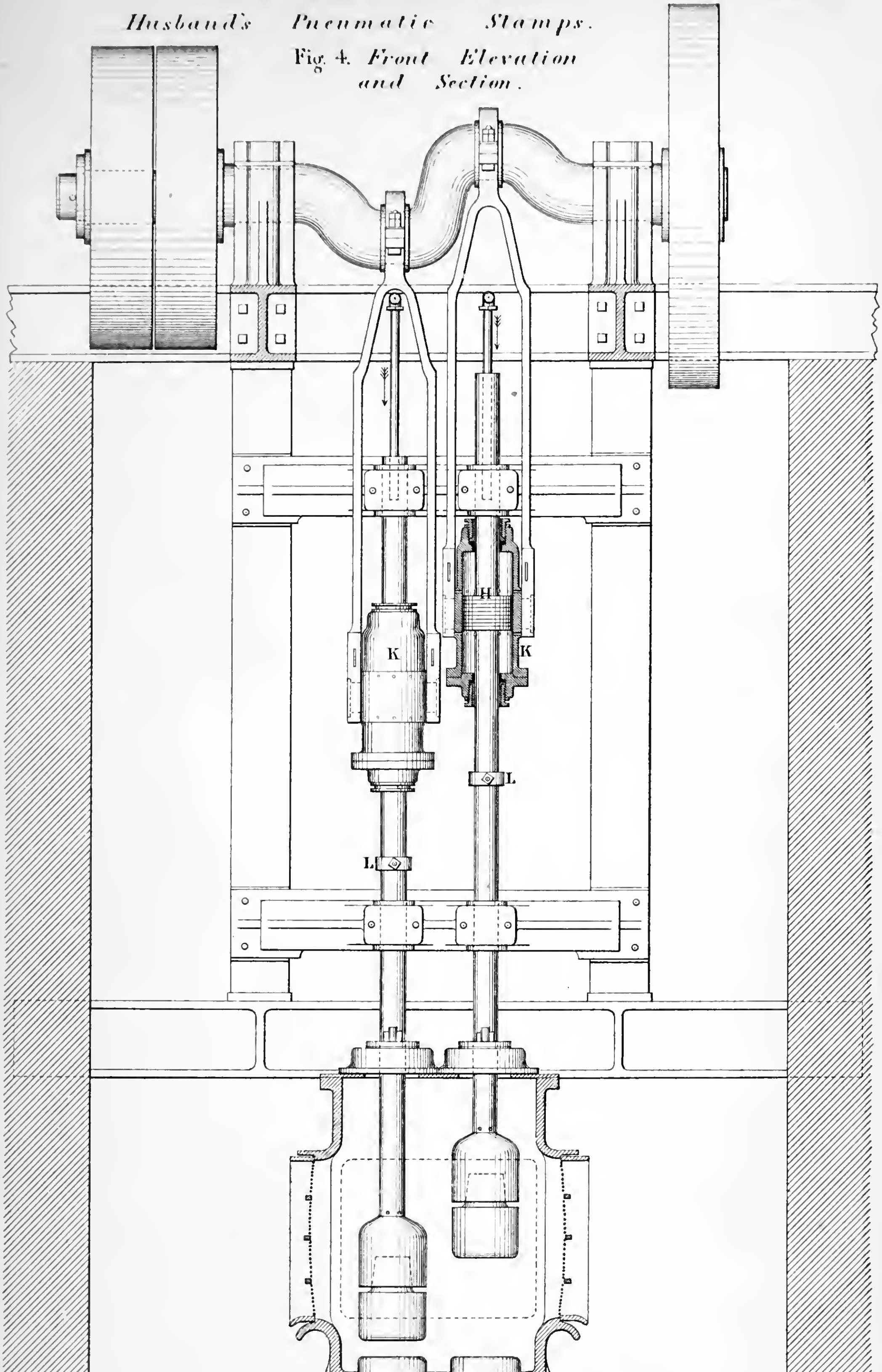
0 5 10 15 20 *Feet.*

(Proceedings Inst. M. E. 1873.)

Plate 38.

Husband's Pneumatic Stamps.

Fig. 4. *Front Elevation and Section.*



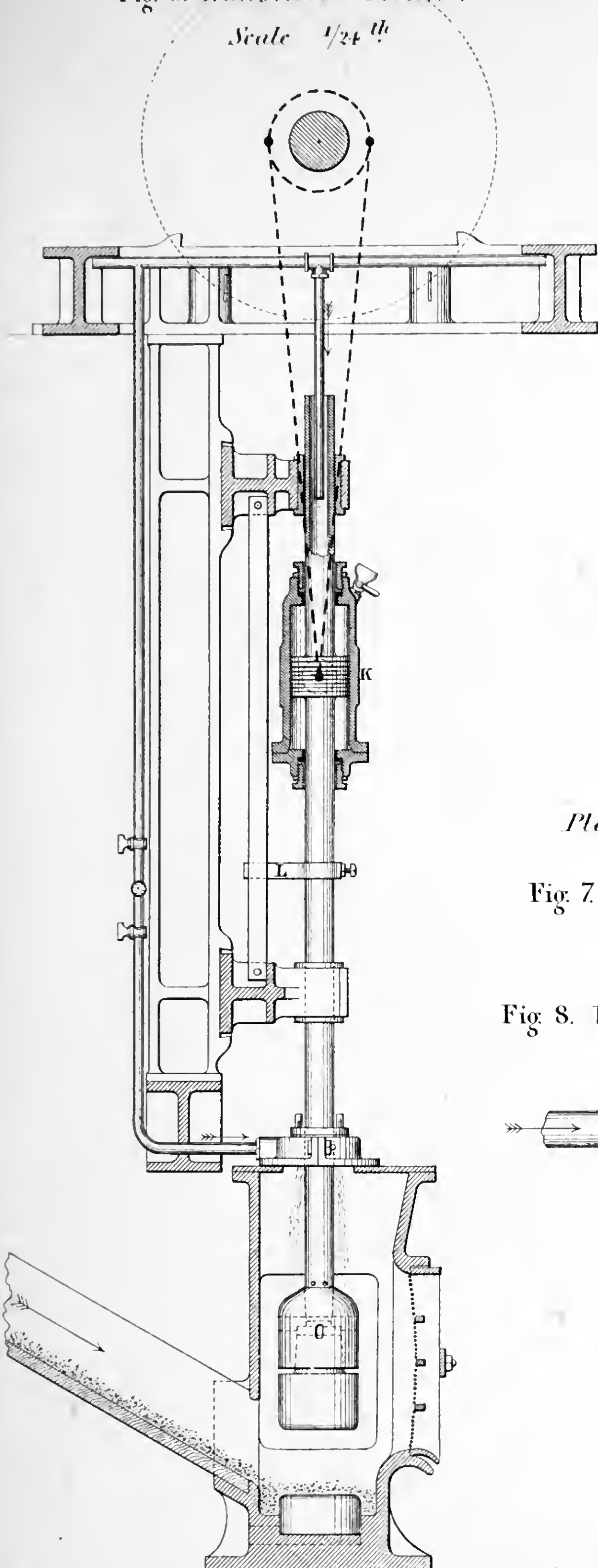
Scale 1/24th.

Ins. 12 6 0 1 2 3 4 5 6 Feet.

Husband's Pneumatic Stamps.

Fig. 5. *Transverse Section.*

Scale 1/24th.

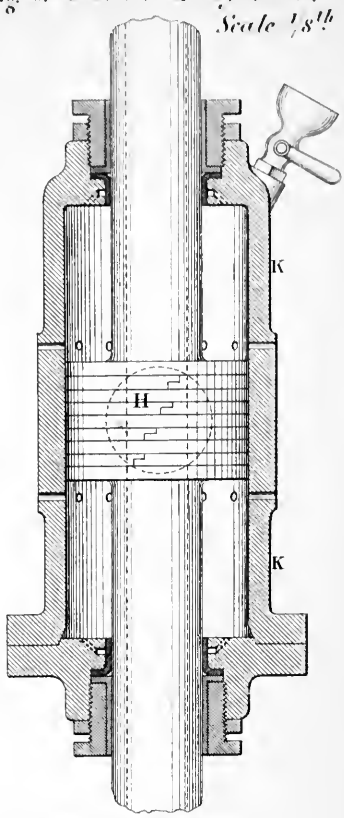


Scale 1/24th.

10 5 0 10 20 30 40 Inches.

Fig. 6. *Section of Cylinder.*

Scale 1/8th.



Plan of Horn for turning Lifter.

Fig. 7.

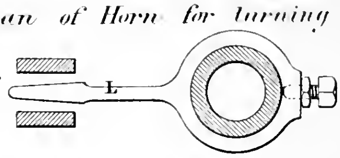


Fig. 8. *Water Supply to Stamp Head.*

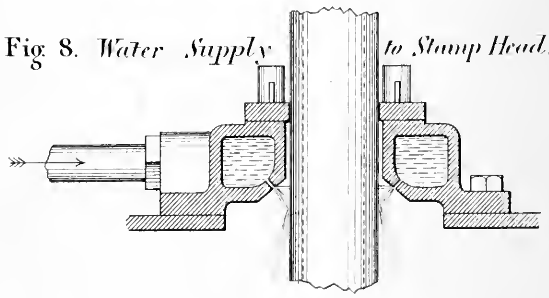
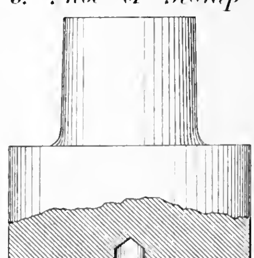


Fig. 9. *Shoe of Stamp Head.*



Scale 1/8th.

(Proceedings Inst. M. E. 1873.)

Ordinary Convex Buddle.

Fig. 10. *Vertical Section.*

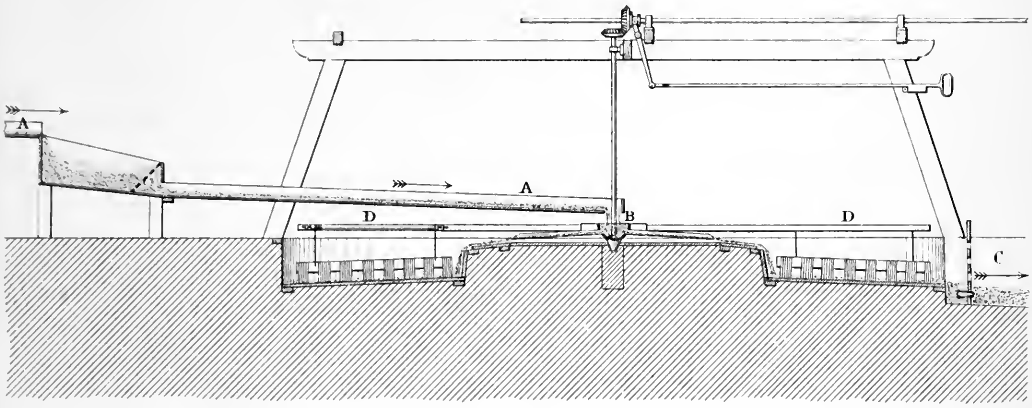
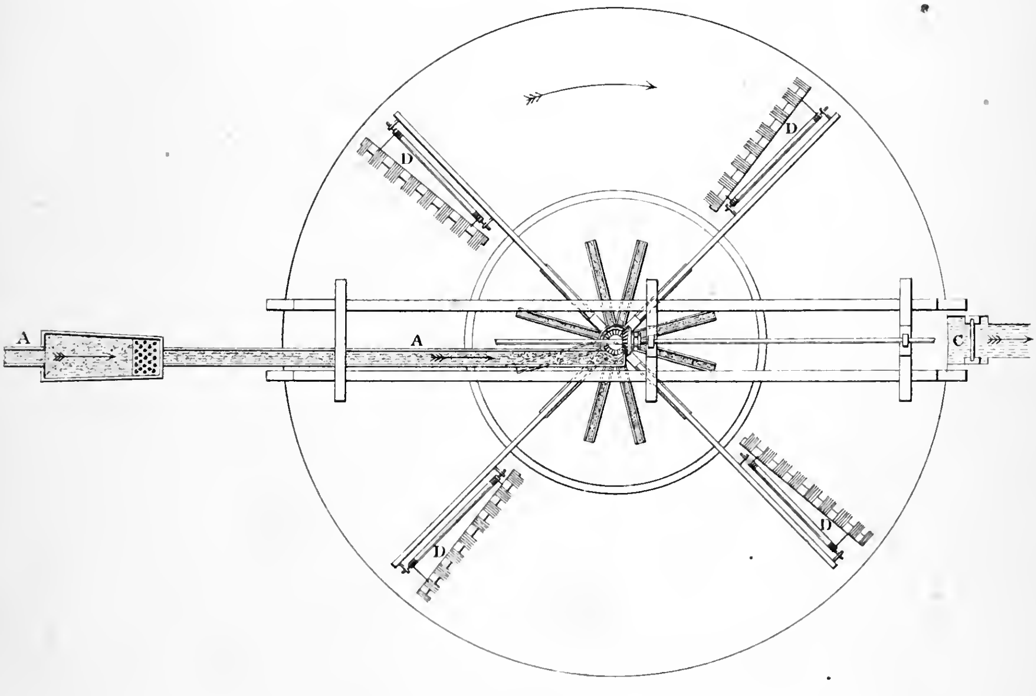


Fig. 11. *Plan.*



Scale $^1/_{100}{}^{th}$

10 5 0 10 20 *Feet.*

ORE DRESSING MACHINERY. *Plate 42.*

Martin's Buddle.

Fig. 12. *Elevation of Revolving Centre Pan.*

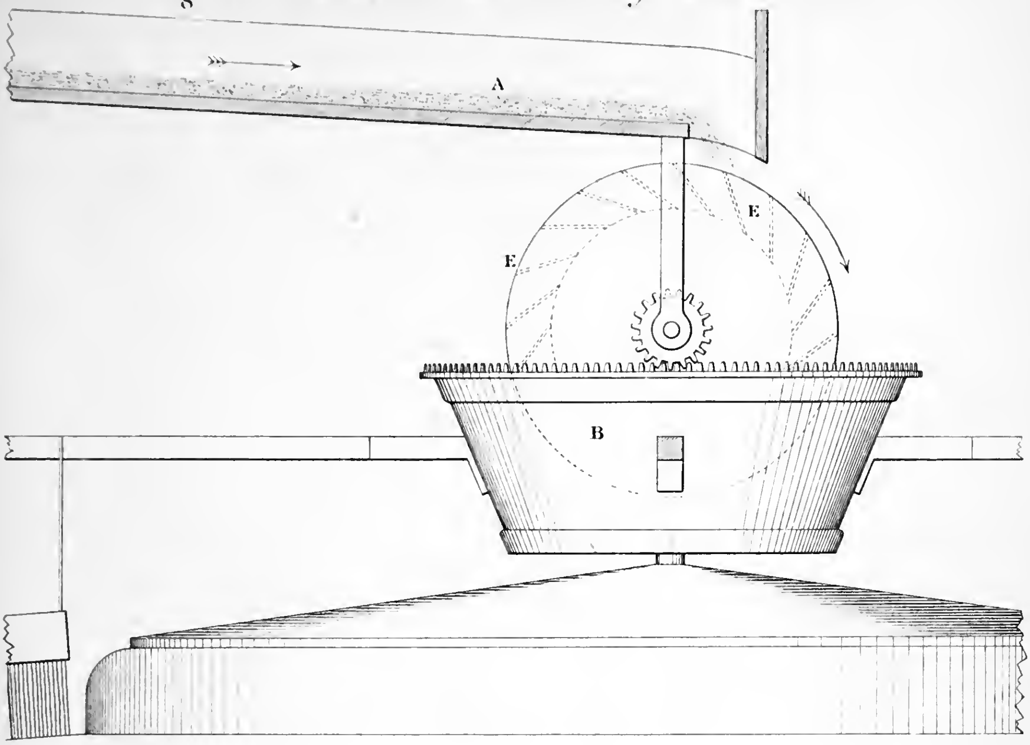
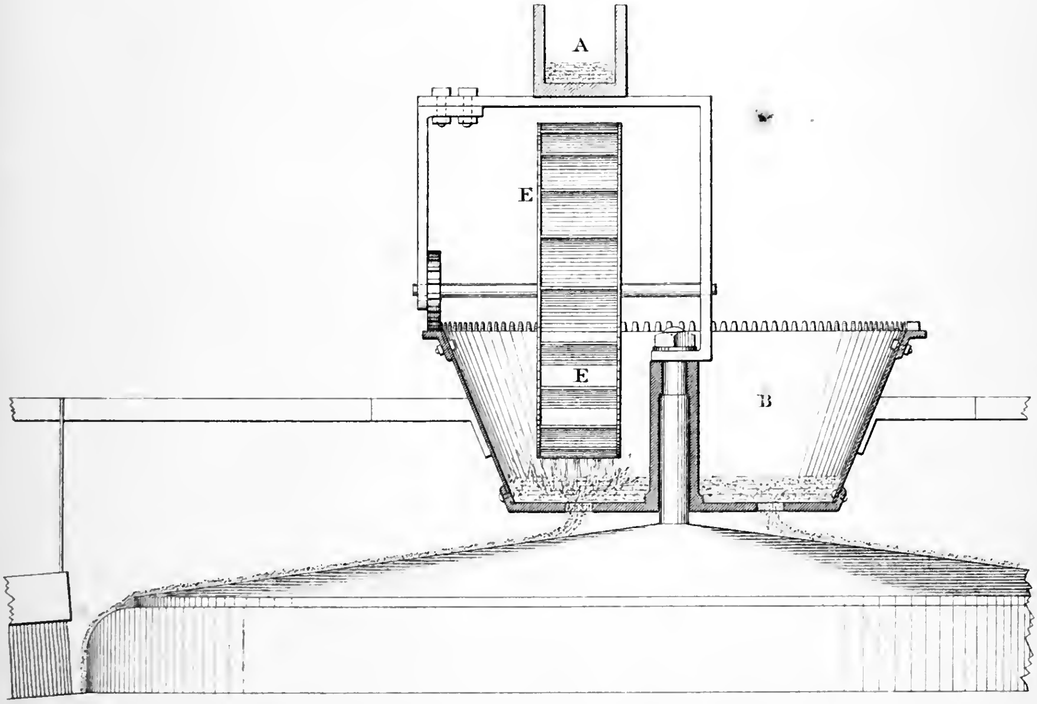


Fig. 13. *Vertical Section.*



(Proceedings Inst. M. E. 1873.)

Scale 1/16th

10 5 0 10 20 30 40 50 *Inches.*

Ordinary Concave Buddle.

Fig. 14. *Vertical Section.*

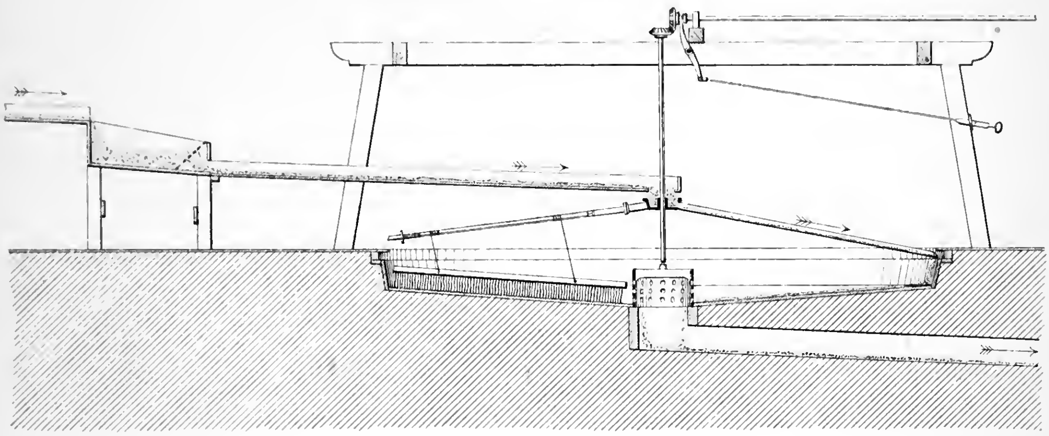
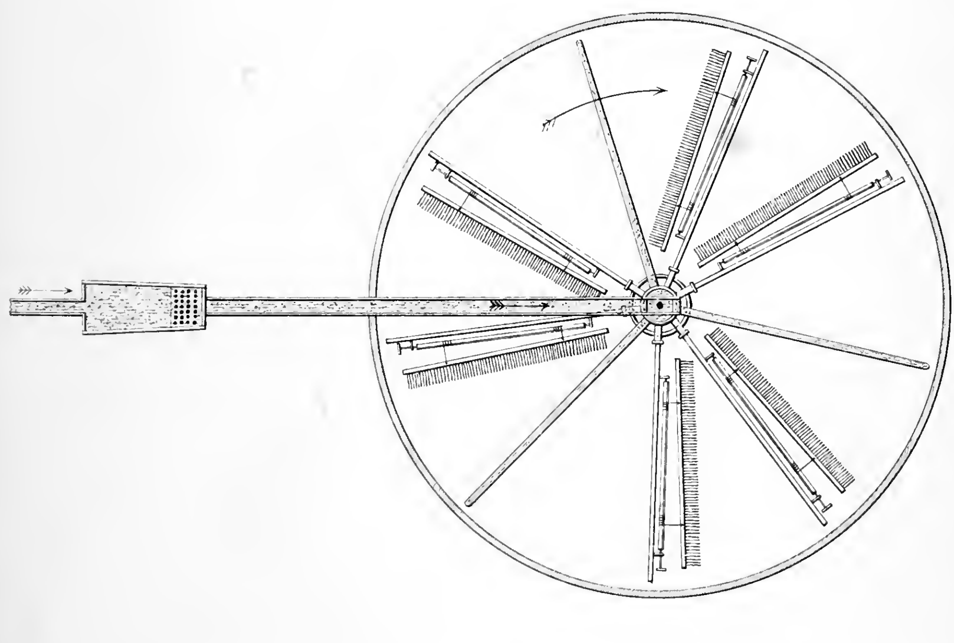


Fig. 15. *Plan.*



(Proceedings Inst. M. E. 1873.)

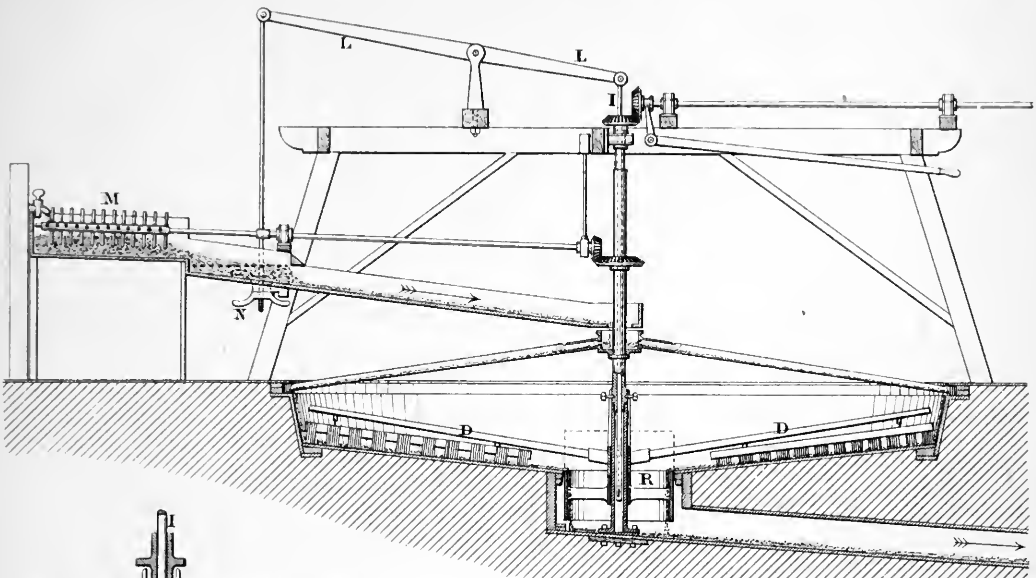
Scale 1/100th

10 5 0 10 20 Feet.

ORE DRESSING MACHINERY.

Borlase's Buddle.

Fig. 16. *Vertical Section.*



Detail of Sliding Ring.

Scale 1/40th.

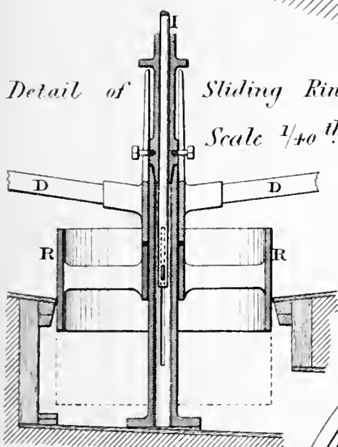
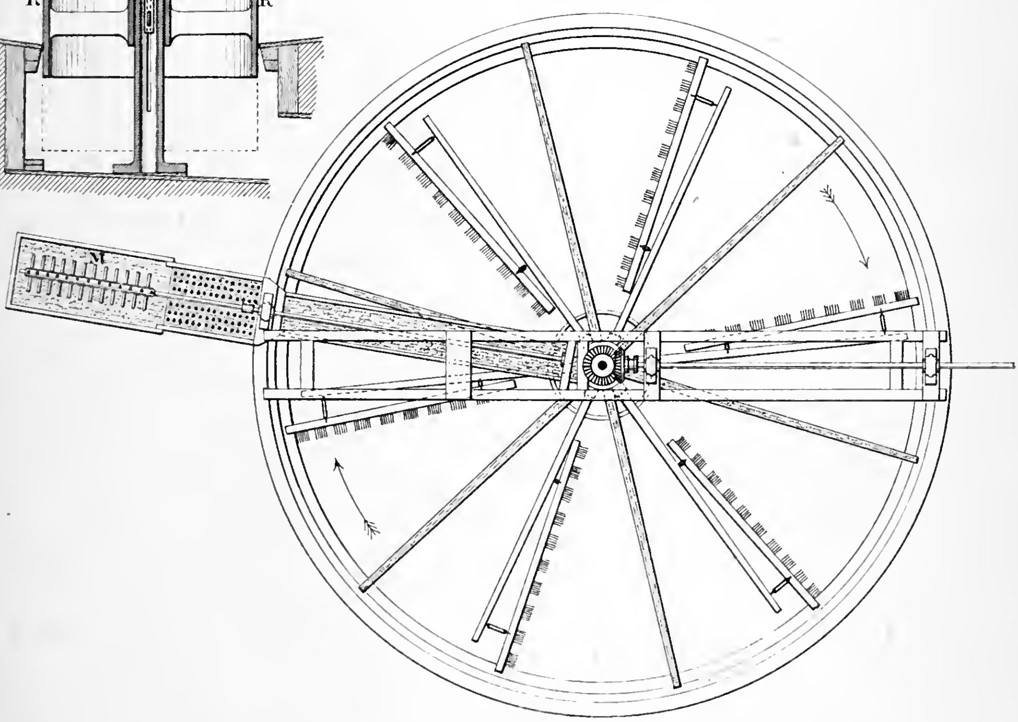


Fig. 17. *Plan.*



(Proceedings Inst. M. E. 1873.)

Scale 1/80th. 0 5 10 15 20 Feet.

Propeller Knife Buddle.

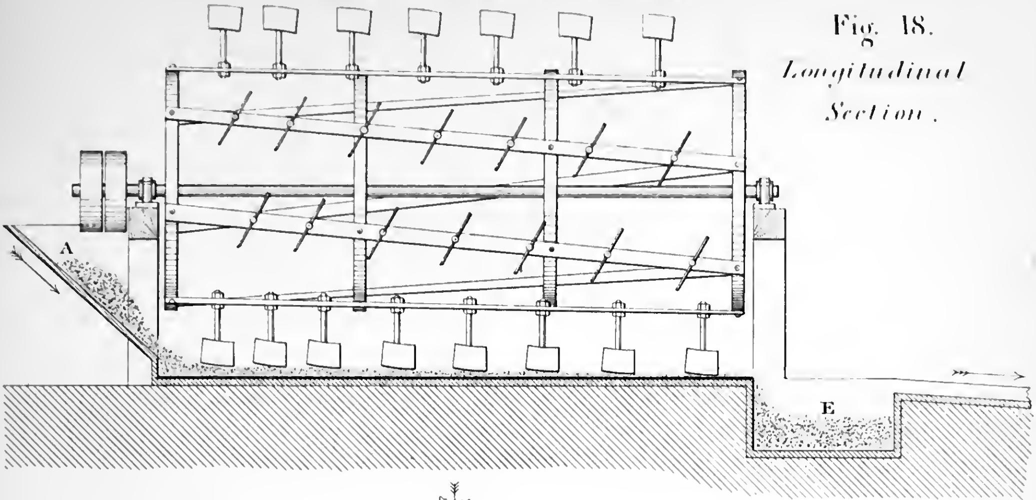


Fig. 18. Longitudinal Section.

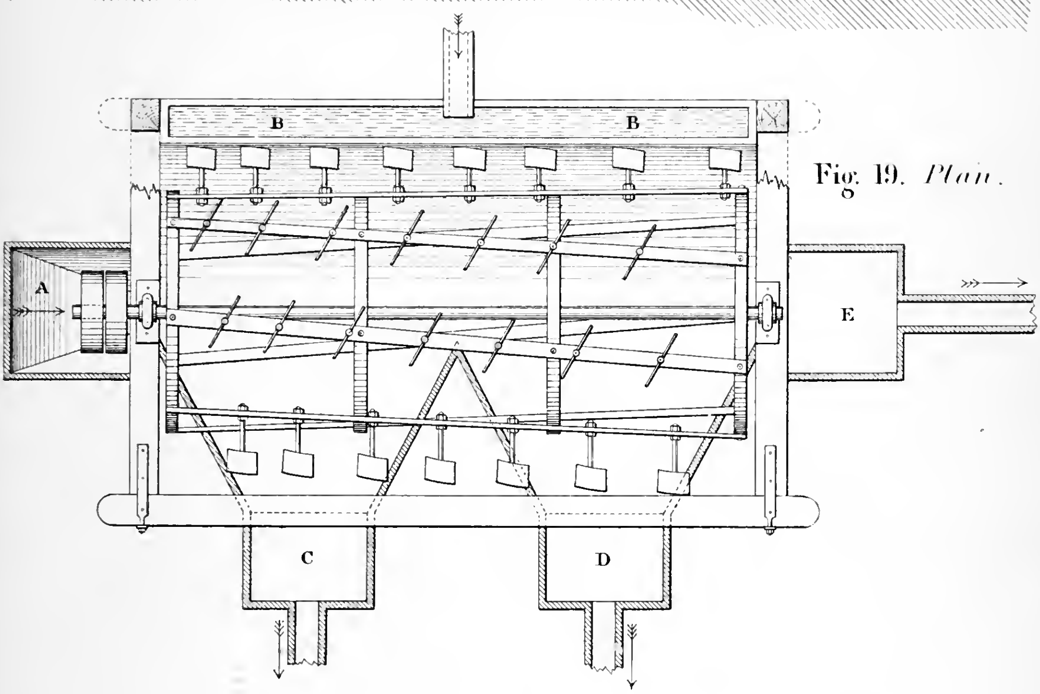


Fig. 19. Plan.

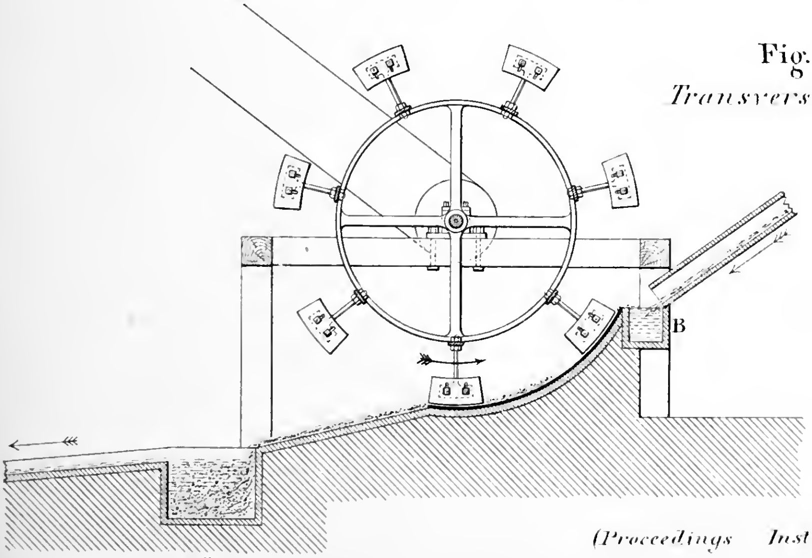


Fig. 20. Transverse Section.

(Proceedings Inst. M. E. 1873.)

Scale 1/50 th

0 5 10 Feet.

Borlase's Revolving Dressing Machine.

Fig. 21. *Vertical Section.*

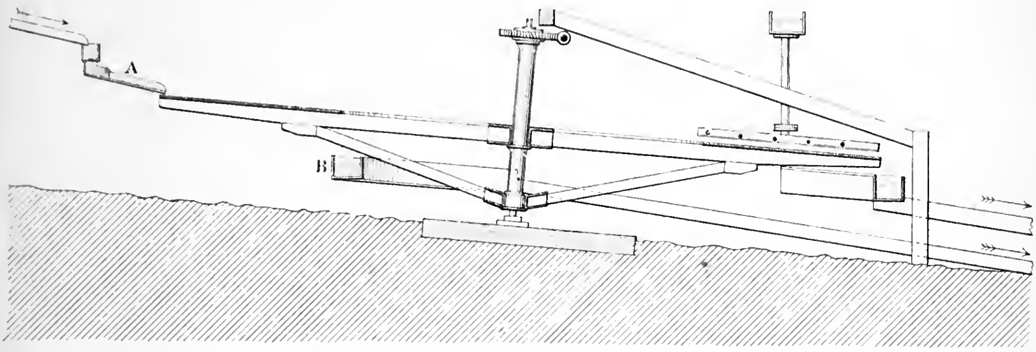
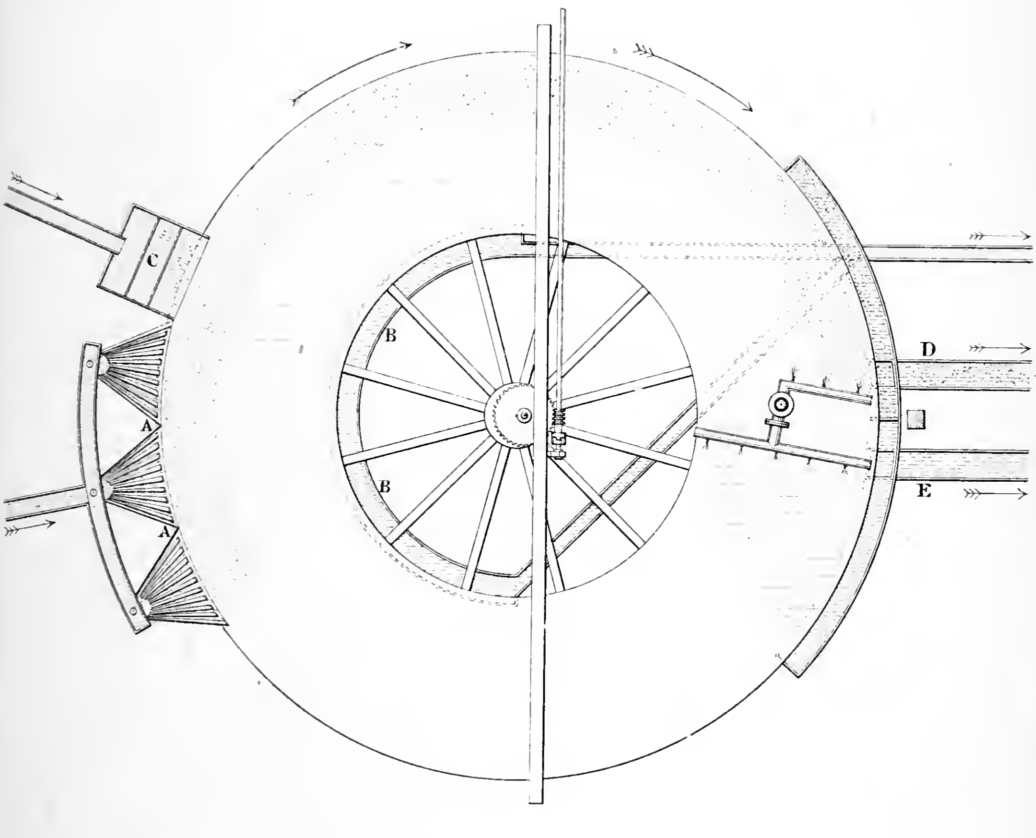


Fig. 22. *Plan.*



Scale $^{1}/_{100}$ *th*

10 5 0 10 20 *Feet.*

[illegible]

ORE DRESSING MACHINERY.

Oxland and Hocking's Calciner.

Fig. 23. *Longitudinal Section.*

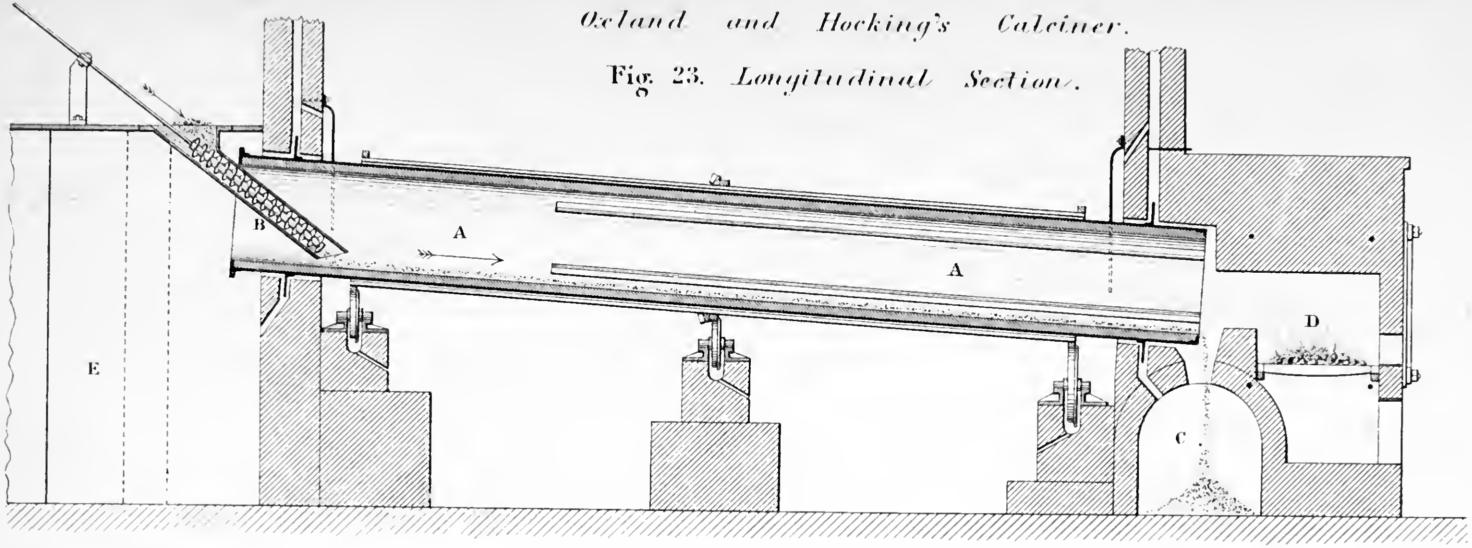


Fig. 24. *Transverse Section.*

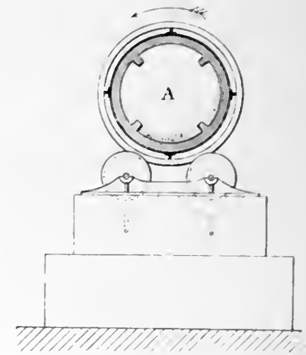
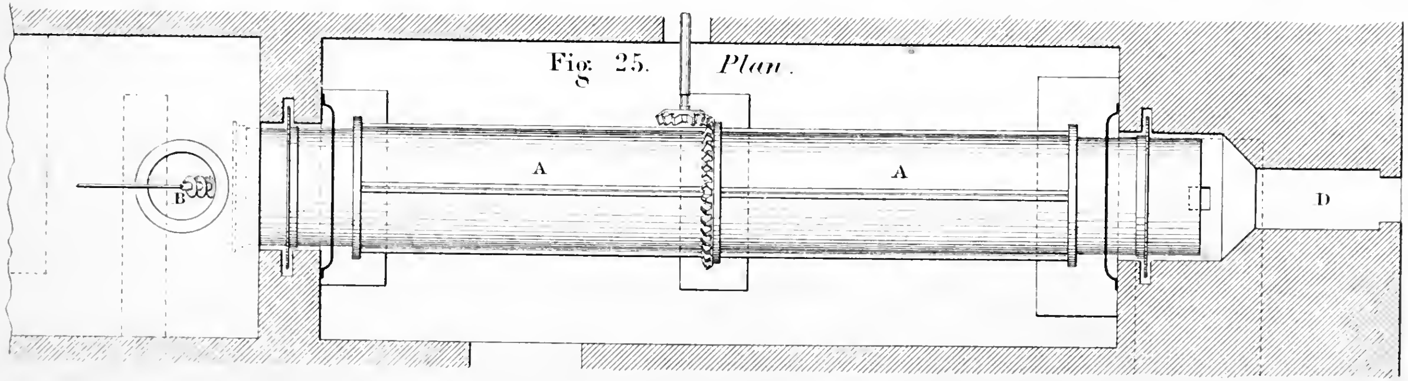


Fig. 25. *Plan.*



(Proceedings Inst. M. E. 1873.) *Scale 1/100 th.* 10 5 0 10 20 Feet.

ORE DRESSING MACHINERY.

Self-Acting Slime Frame.

Fig. 26. *Longitudinal Section.*

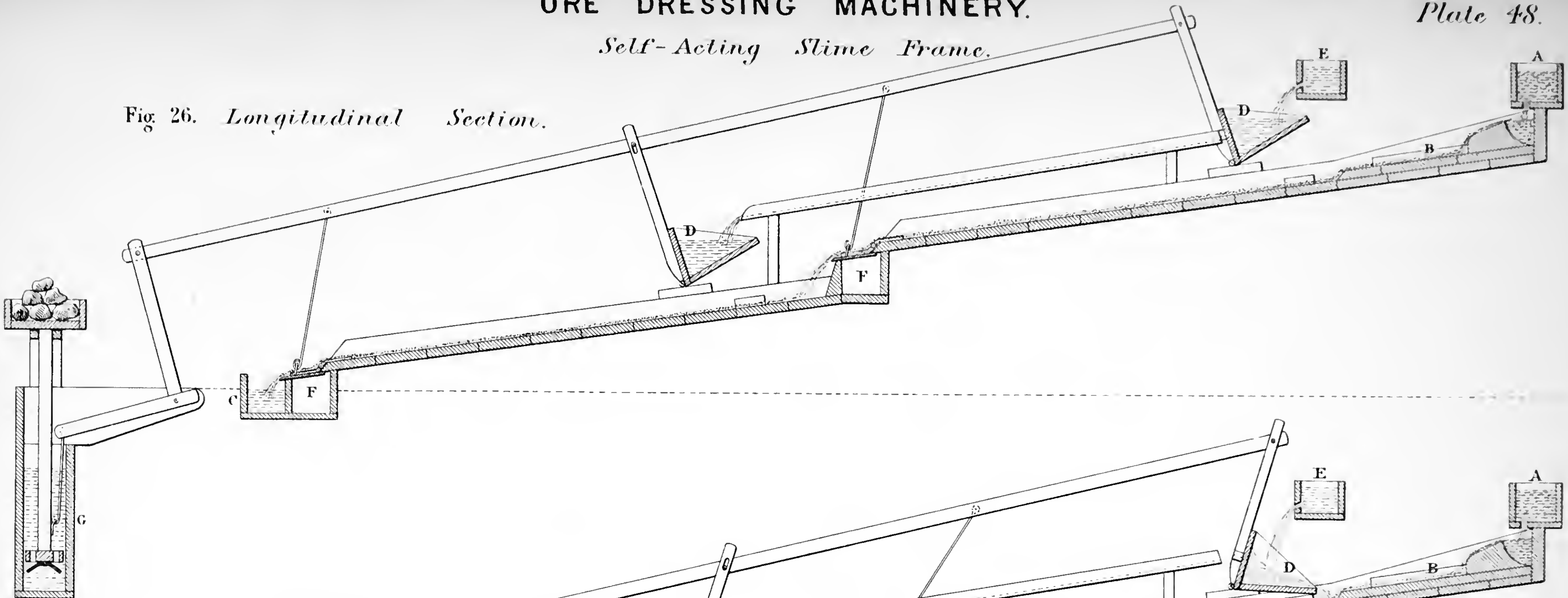
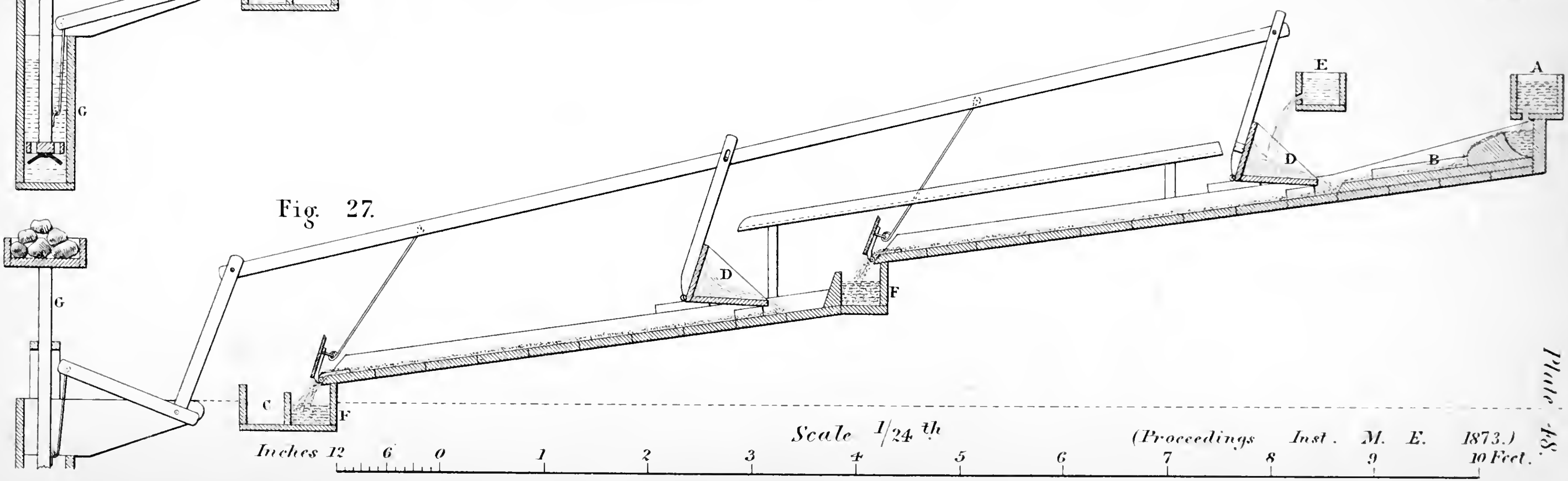


Fig. 27.



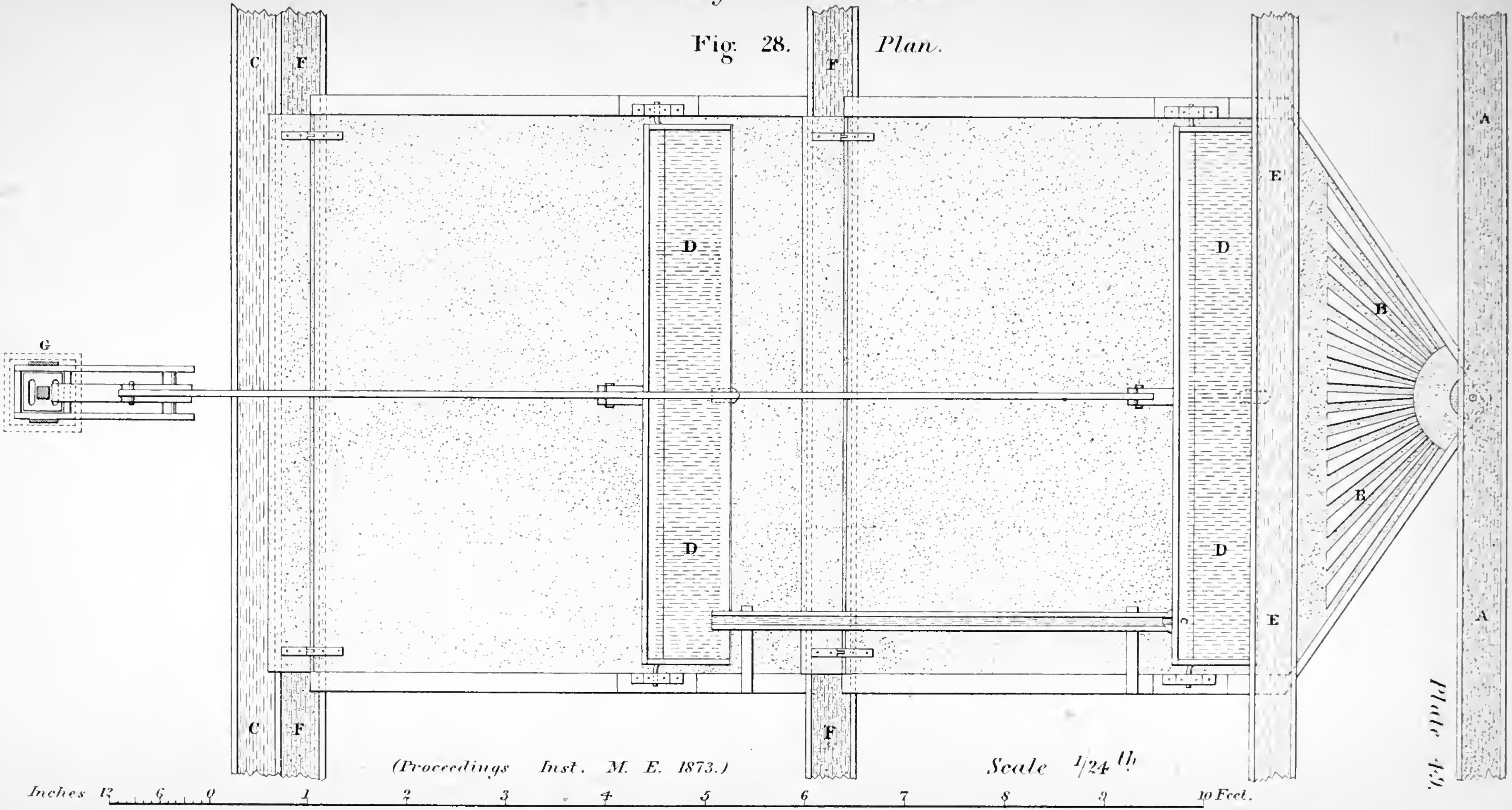
(Proceedings Inst. M. E. 1873.)

Plate 48.

ORE DRESSING MACHINERY.

Self-Acting Slime Frame.

Fig. 28. *Plan.*



(*Proceedings Inst. M. E. 1873.*)

Scale 1/24 th

Plate 49.

ORE DRESSING MACHINERY. *Plate 50.*

Dingey's Pulveriser.

Fig. 29. *Elevation.*

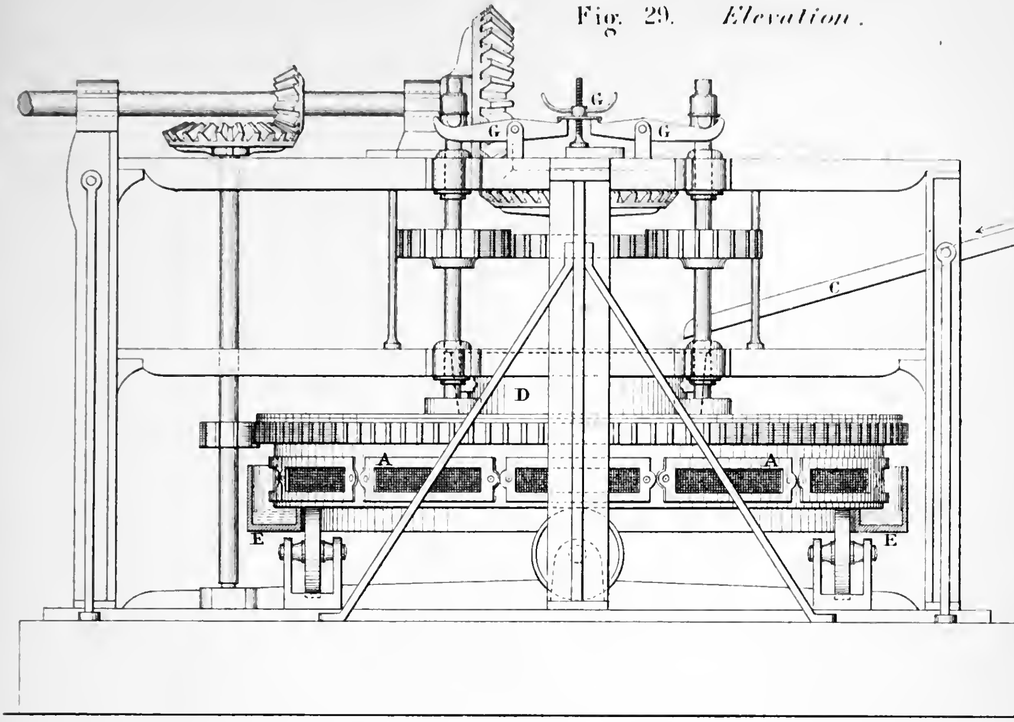
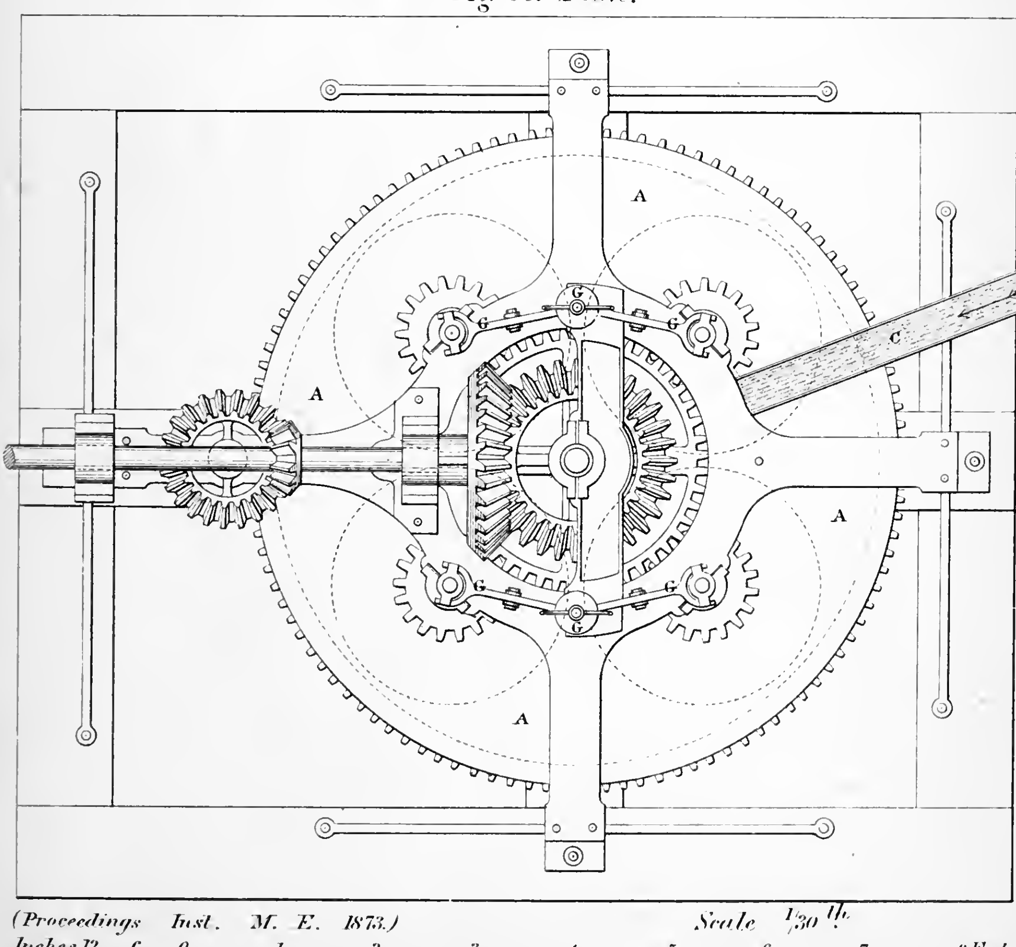


Fig. 30. *Plan.*



(*Proceedings Inst. M. E. 1873.*) *Scale* $1/30$*th.*

Inches 12 6 0 1 2 3 4 5 6 7 8 *Feet.*

Dingey's Pulveriser.

Fig. 31. *Vertical Section.*

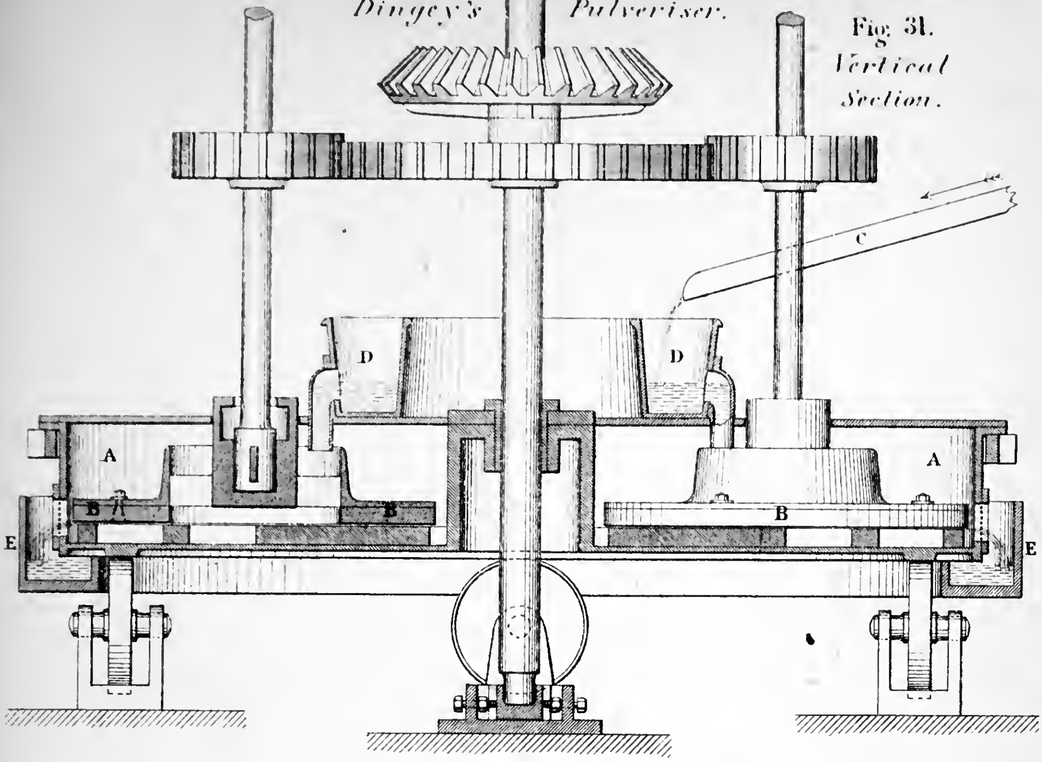
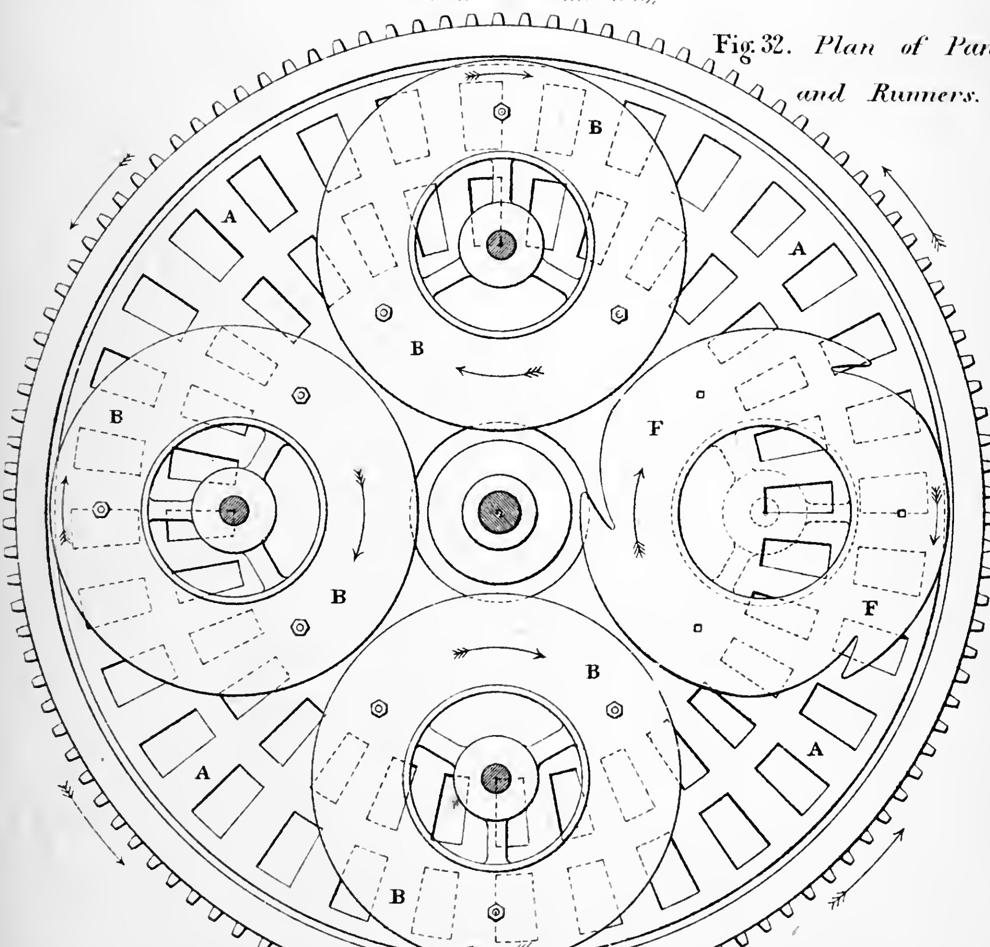


Fig. 32. *Plan of Pan and Runners.*



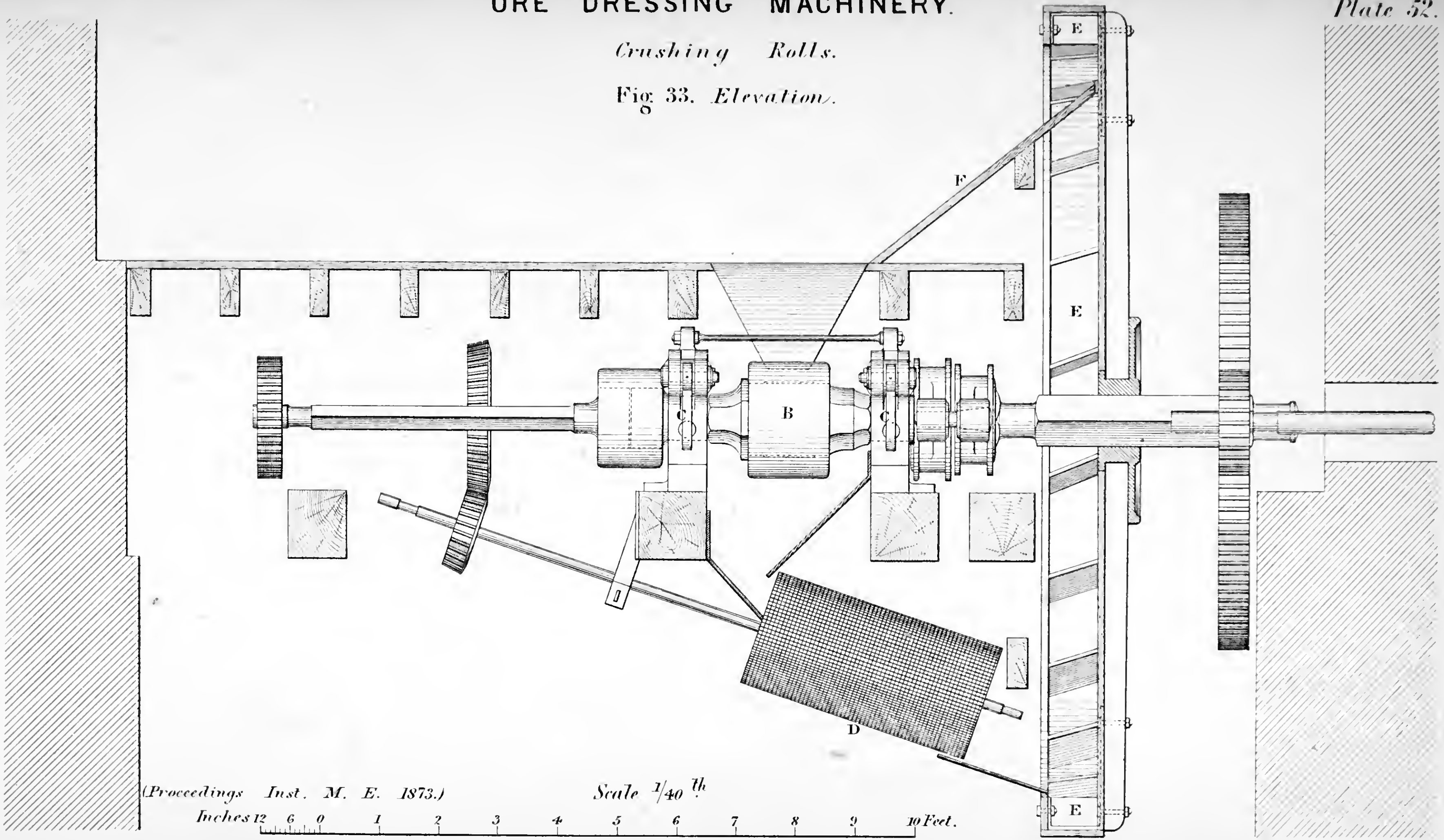
(Proceedings Inst. M. E. 1873.) *Scale 1/20 th*

Inches 12 6 0 1 2 3 4 5 *Feet.*

ORE DRESSING MACHINERY.

Crushing Rolls.

Fig. 33. *Elevation.*



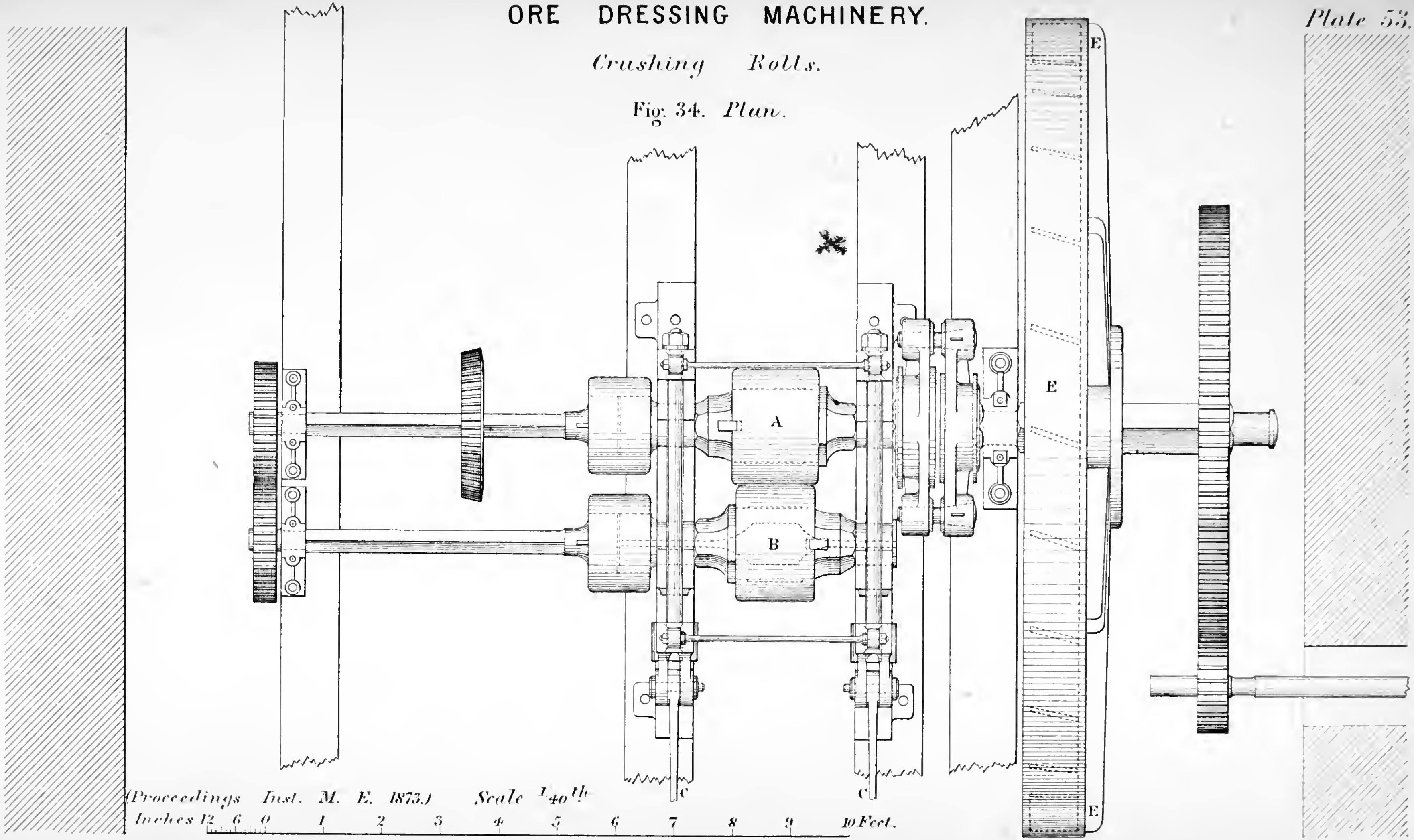
(Proceedings Inst. M. E. 1873.)

Plate 52.

ORE DRESSING MACHINERY.

Crushing Rolls.

Fig. 34. *Plan.*



(Proceedings Inst. M. E. 1873.) *Scale 1/40th*

Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet.

Plate 53.

Plate 54.

ORE DRESSING MACHINERY.

Crushing Rolls.

Fig. 35. *Transverse Section.*

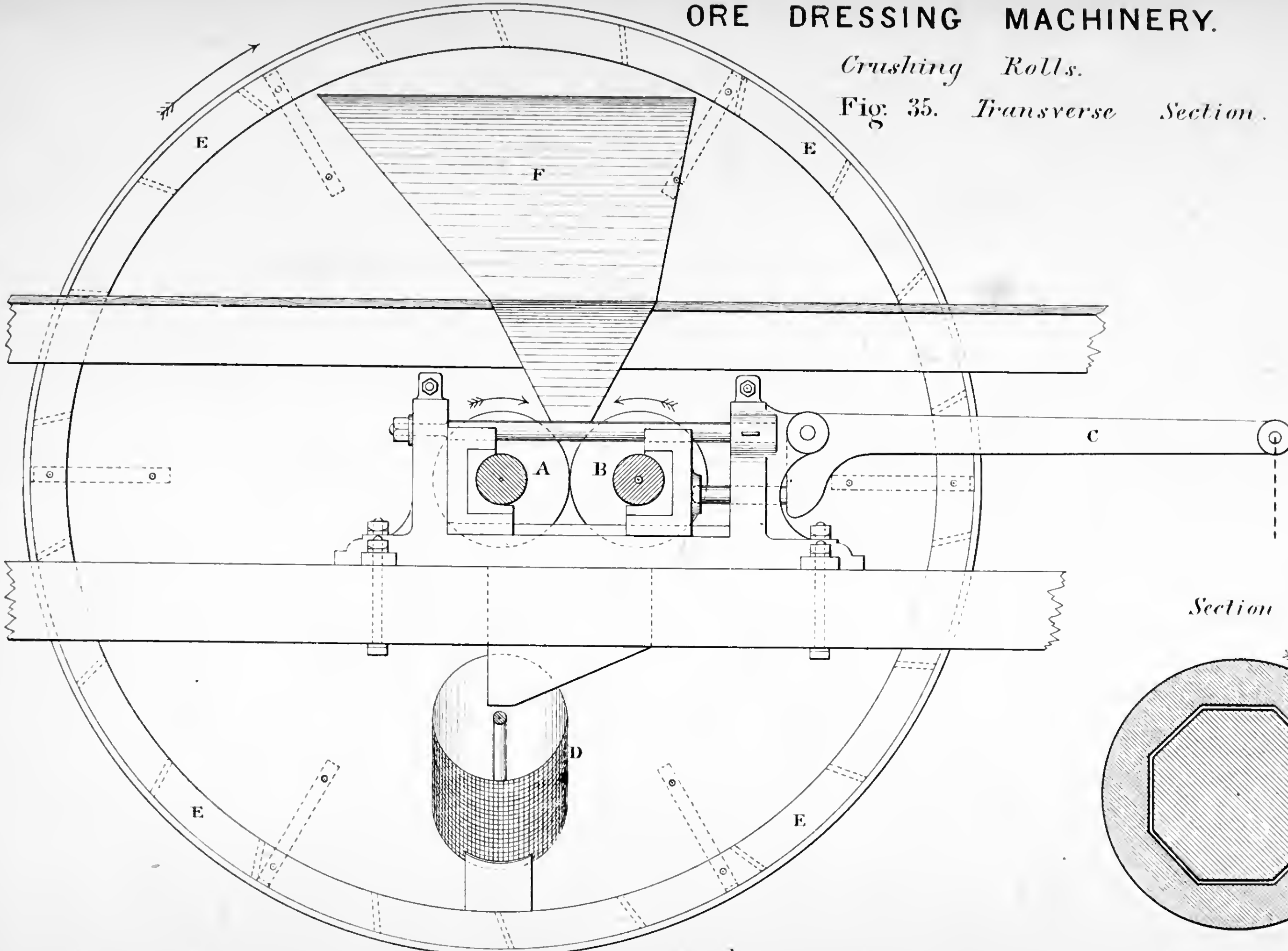
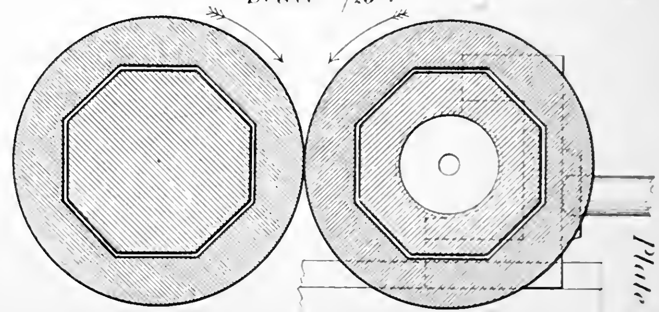


Fig. 36.
Section of Rolls and Spindles.
Scale 1/20th



Scale 1/40th Inches 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet.

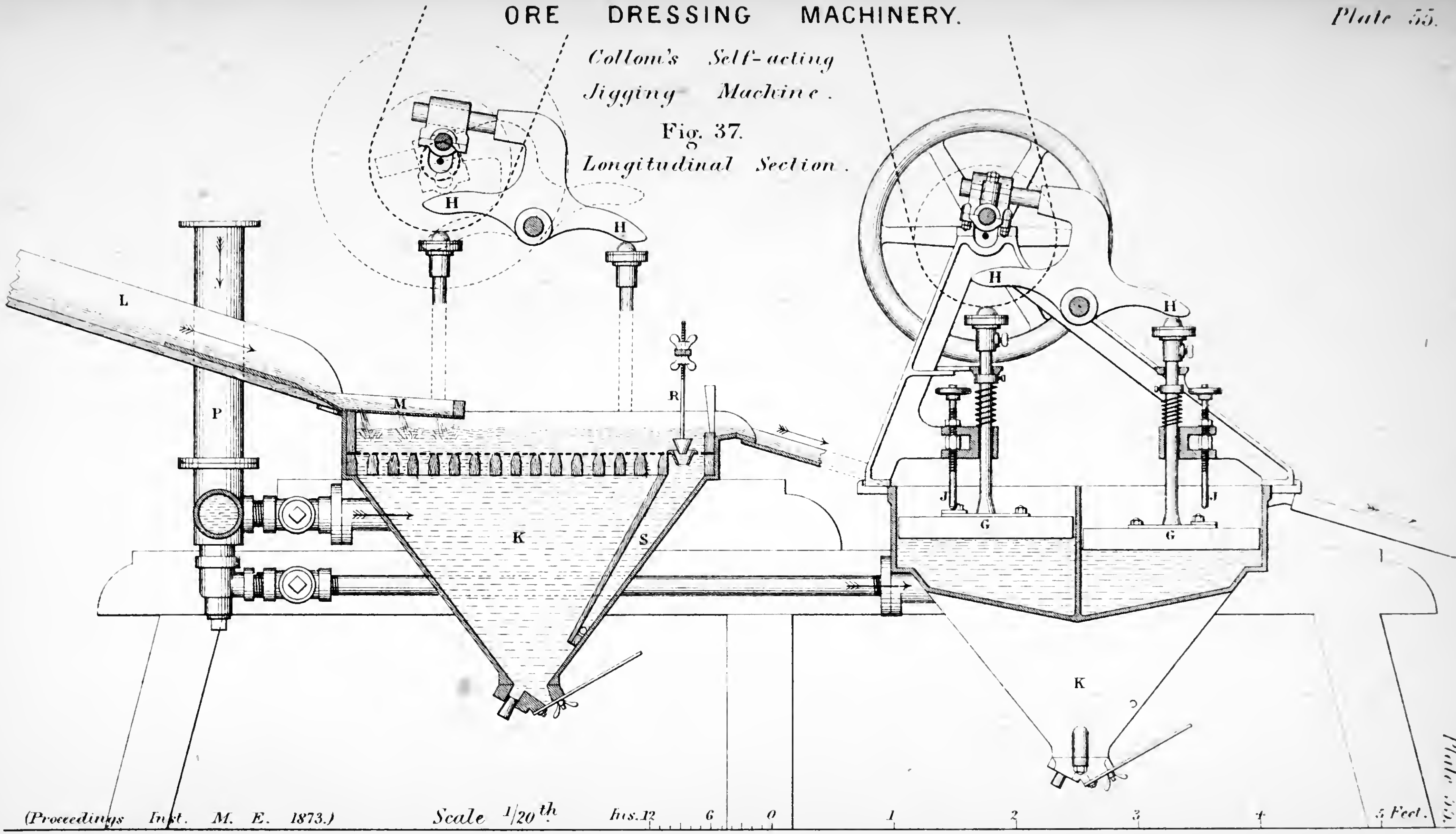
Plate 54.

ORE DRESSING MACHINERY.

Collom's Self-acting Jigging Machine.

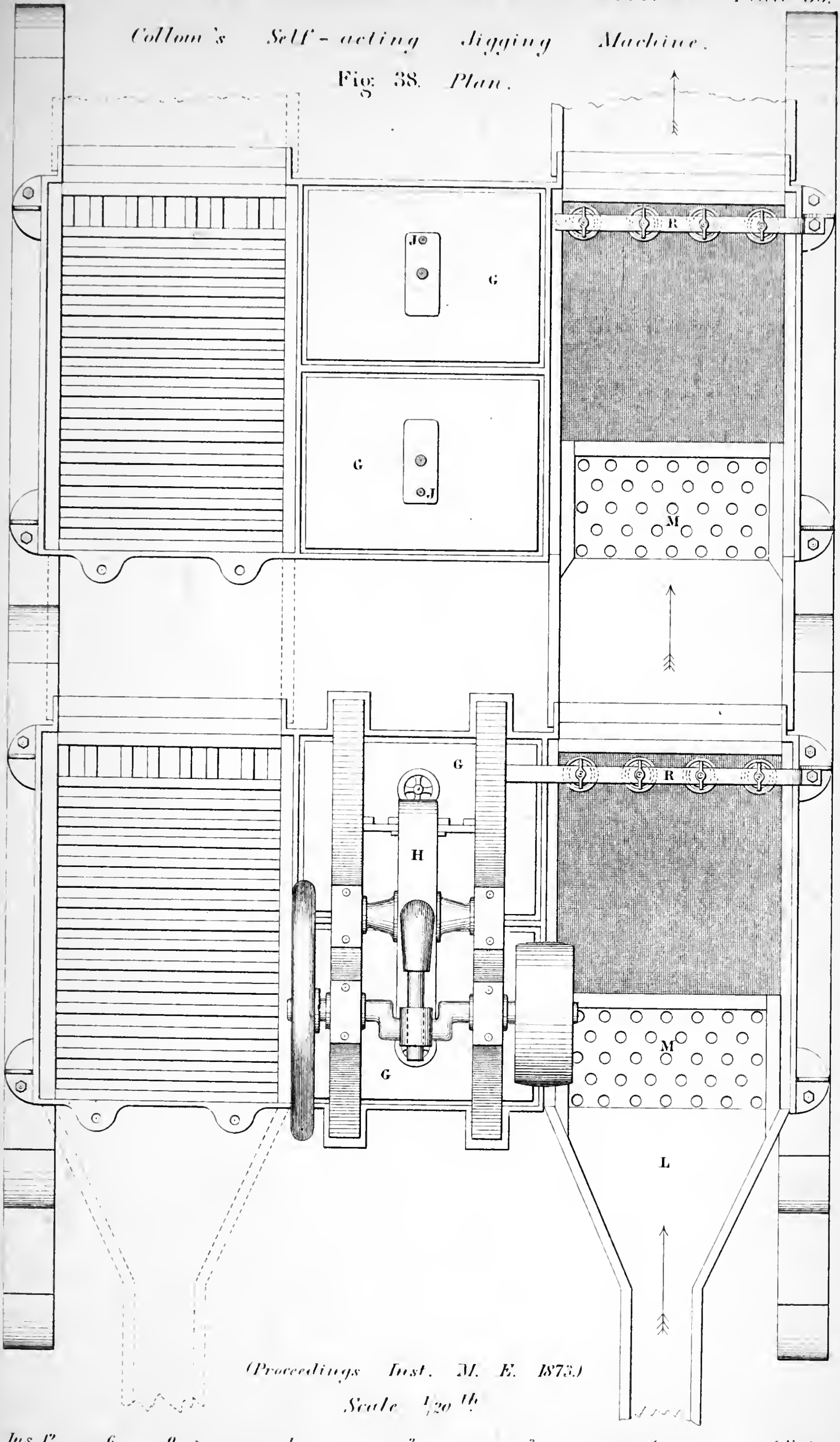
Fig. 37.

Longitudinal Section.



Collom's Self-acting Jigging Machine.

Fig. 38. *Plan.*



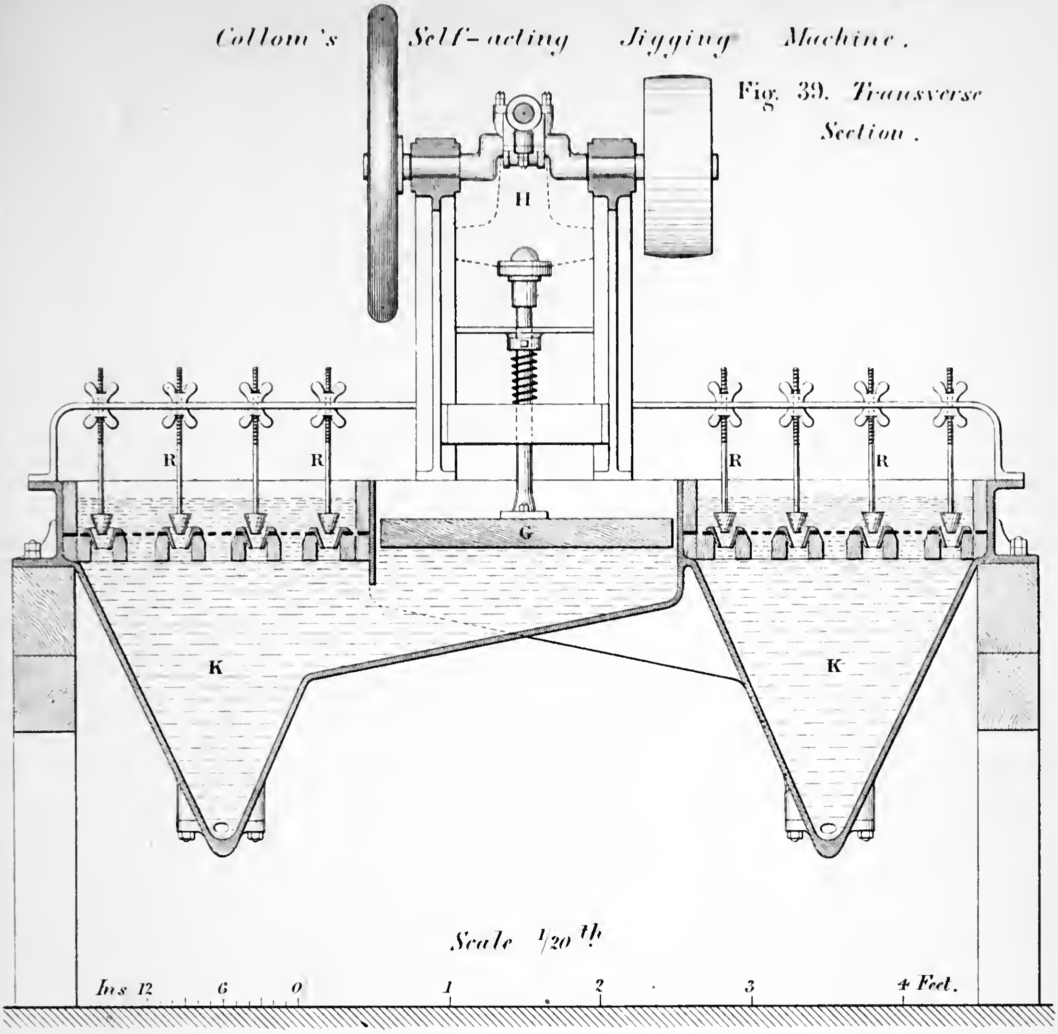
(Proceedings Inst. M. E. 1873.)

Scale $\frac{1}{20}$ th.

Ins. 12 6 0 1 2 3 4 5 Feet.

Collom's Self-acting Jigging Machine.

Fig. 39. Transverse Section.



Hand Jigging Machine.

Fig. 40. Longitudinal Section.

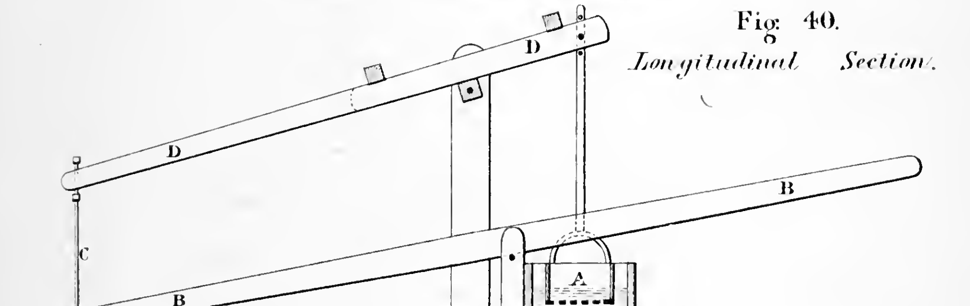
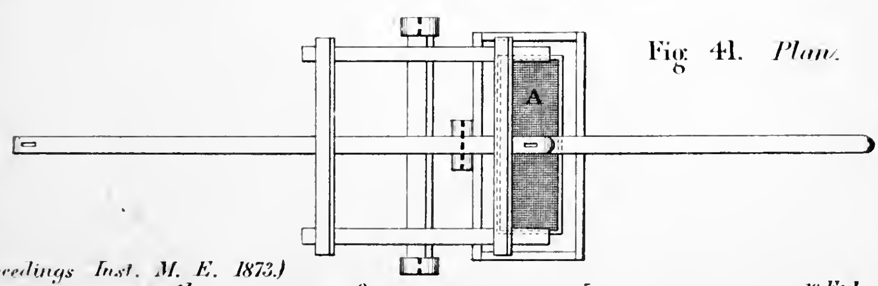


Fig. 41. Plan.



(Proceedings Inst. M. E. 1873.)

Scale 1/60th

0 5 10 Feet.

RESTRONGUET TIN STREAM WORKS.

Fig. 1. Plan.

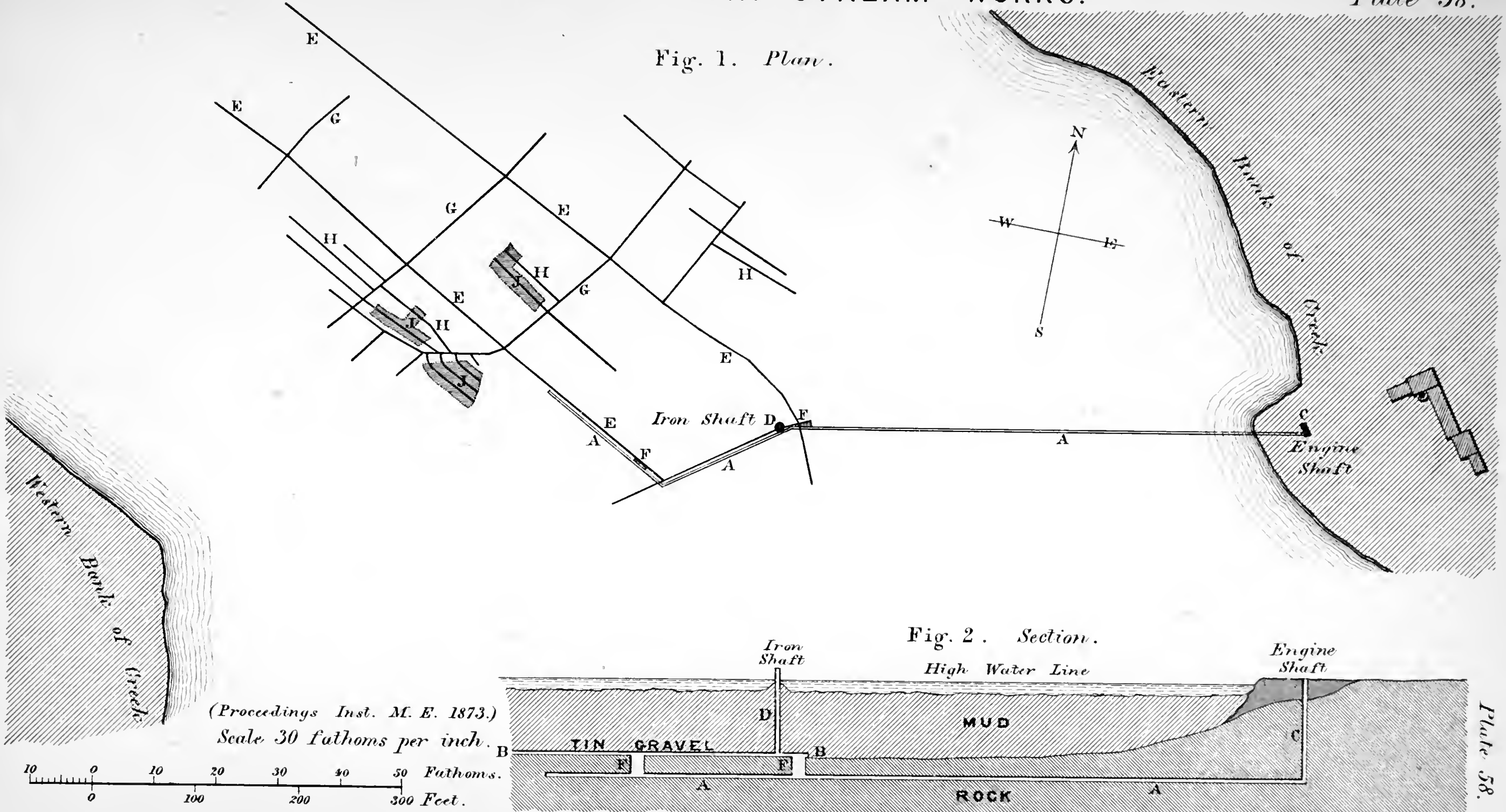


Fig. 2. Section.

(Proceedings Inst. M. E. 1873.)

Scale 30 fathoms per inch.

Plate 58.

Slime Separator.

Fig. 3. *Longitudinal Section.*

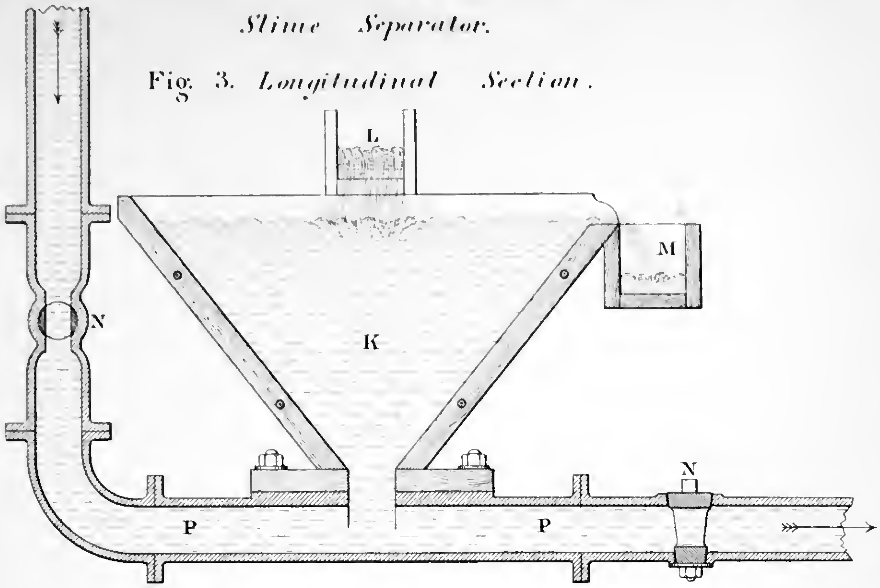


Fig. 4. *Plan.*

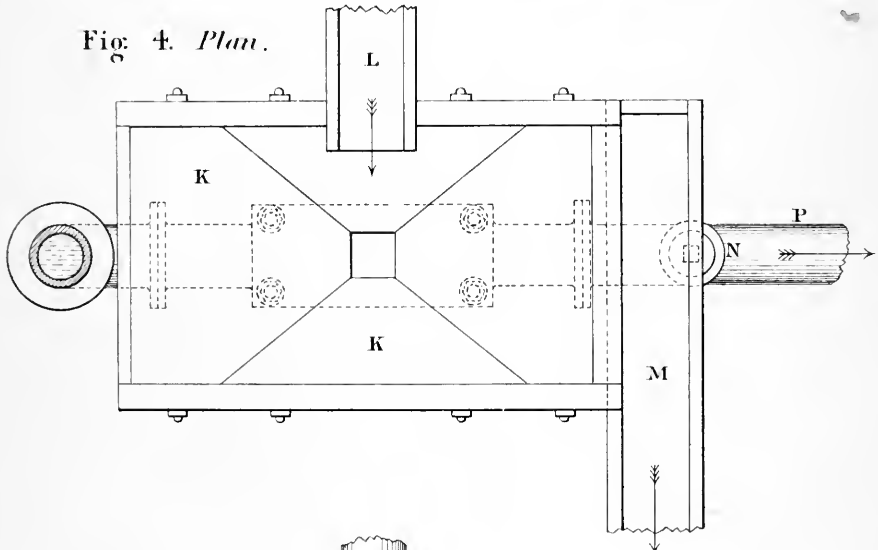
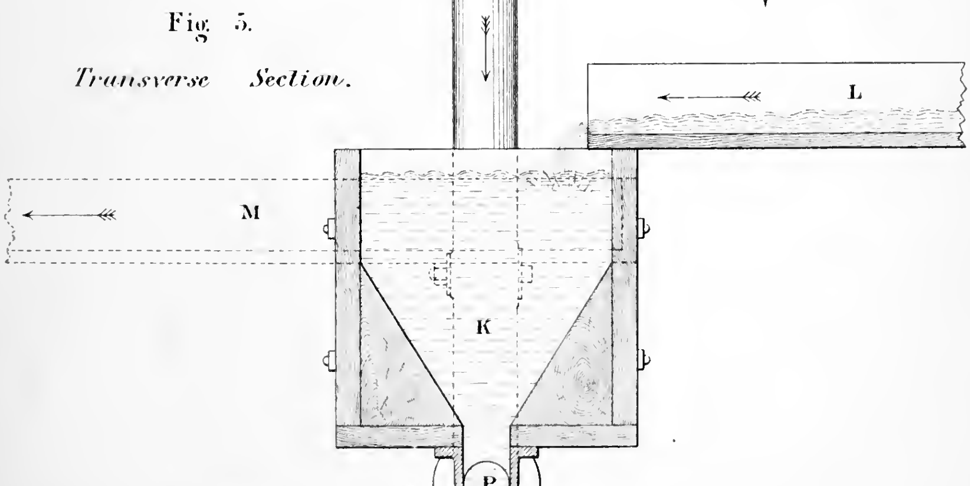


Fig. 5.

Transverse Section.



Scale 1/16th. Ins. 12 6 0 1 2 Feet.

PROCEEDINGS.

29 and 30 July, 1873.

The Annual Meeting of the Members was held in St. John's Hall, Penzance, on Tuesday, 29th July, 1873; Frederick J. Bramwell, Esq., F.R.S., Vice-President, in the Chair.

The Chairman was sorry to announce that the President, Mr. Siemens, was unable to attend this meeting, as he was detained in Vienna, where however he was advancing the interests of Mechanical Engineering by presiding over the deliberations of the Jury who had to award the prizes for improvement in that art, and where also he was to a still greater extent advancing those interests as Chairman of the International Patent Congress. A letter had been received from Mr. Siemens, in which he expressed the great regret his unavoidable absence had caused him.

The Minutes of the last Meeting were read and confirmed.

The Chairman announced that the Ballot Lists had been opened, and the following New Members were found to be duly elected:—

MEMBERS.

George Baird,	St. Petersburg.
Charles Jordan Bradbury,	Manchester.
William Tarleton Bury,	Sheffield.
Henry Holt Butterfill,	Hull.
William Talbot Cheesman,	Hartlepool.
Henry Davey,	Leeds.
David Davy,	Sheffield.
James A. C. Hay,	Woolwich.
Lawrance Headly,	Cambridge.

T

John Albert Reinhold Hildebrandt, .	Manchester.
Charles Horsley, ...	London.
Richard Hoskin, ...	Cirencester.
Edward Trygarn Jones, ...	London.
William Hely Llewellyn, ...	Bridgend.
John Edgar Lowe, ...	London.
Peter T. Möller, ...	St. Petersburg.
Richard Christopher Rapier, . . .	London.
Alfred Austin Rickaby, ...	Sunderland.
William George Strype, ...	Dublin.
John Taylor, ...	Nottingham.
William Lawrence Williams, . . .	Edinburgh.
John Proctor Woodhead, ...	Manchester.

ASSOCIATES.

John Alfred Griffiths, ...	London.
John Robinson Whitley, ...	Leeds.

The following paper, communicated through Sir Frederick M. Williams, Bart., M.P., was then read :—

ON THE MINING DISTRICT OF CORNWALL AND WEST DEVON.

By Mr. J. HENRY COLLINS, F.G.S., of St. Austell.

The geological structure of the Mining District of Cornwall and West Devon is of great interest, and, in its broad outlines, very simple. The principal geological features of the district are indicated in the general map, Fig. 1, Plate 22. The fundamental rock is a mass of granite extending from Dartmoor to the Land's End, a distance of nearly 100 miles, if not 25 miles further to the Scilly Isles. This granite is for the most part overlaid by other rocks of various kinds, but it appears at the surface in five large masses and several smaller ones, which form the highest land of the district; rising gradually from hills of about 500 feet height in the extreme west to others of three times that height in Dartmoor. The granite throughout this large tract of country, with a few merely local exceptions, is essentially the same in mineralogical character; consisting of glassy quartz, generally of a somewhat smoky tint, grey or white felspar, and dark coloured mica. Near the junctions of the granite with the slaty rocks, another mineral known as schorl or "cockle" is often very abundant. This is a hard, glossy, brittle, and dark-coloured substance, and is very frequently associated with tin ore, with which indeed it may very easily be confounded by the inexperienced, though not more than half as heavy as tin ore. Its presence is considered a fair indication of tin in granite districts; while in slate districts a soft green mineral called chlorite or "peach" is regarded as a good indication.

A kind of clay-slate, locally termed "killas," rests upon the flanks of the granite masses, and partially fills up the hollows between them. This killas is very variable in its appearance and

composition in different parts of the district; but generally it seems to be more highly crystalline near the granite than at a distance from it. The junction of the two rocks is well seen at many points upon the coast, and in several of the mines, especially in those lying to the north of Carn Brea Hill near Camborne. In some places the granite is seen curiously penetrating the slate in the form of veins, as at Wicca Pool in Zennor, Tremearne in Breage, and especially on the north-west flank of St. Michael's Mount, near Penzance. Some of these veins are very large, and they occasionally enclose fragments of slate not at all differing in appearance from the main mass in the immediate neighbourhood. The original lines of "bedding" of the slate are not always easily determined, in consequence of the rock being so highly metamorphosed; they are also frequently much obscured by cleavage and jointing. On the whole however the slaty rocks appear to rest upon an irregular surface of granite in planes generally conformable to the present surface of the country, and to dip mostly away from the central masses of granite.

A section is shown in Fig. 2, Plate 23, taken about half way across the county from south to north for 8 miles length on the line Y in the map, Fig. 1, and drawn to a natural scale of $2\frac{1}{2}$ inches per mile. This section extends from Carn Marth to the coast at St. Agnes' Beacon, the latter being a hill of granite mostly coated with killas. The section shows the position of the slaty rocks resting upon the flanks of the granite; it also shows some of the chief metal-bearing lodes and elvan-courses in cross section. It will be seen that some of these dip or "underlie" to the north; others to the south.

The section shown in Fig. 3, which is continuous in the five Plates 24—28, and is of about $2\frac{1}{2}$ miles length, is taken from south to north through several of the mines adjacent to Carn Brea Hill on the line Z in Fig. 1, drawn to a natural scale of 60 fathoms per inch; it shows the lodes and elvans in detail as proved in these mines, and the shafts and levels of the mine workings. For this section the writer is indebted to Capt. John Maynard, of East Pool mine near Redruth.

In the western part of this great mining district—that is, west of Truro—organic remains are unknown; but to the eastward, fragmentary corals, crinoids, trilobites, brachiopods, and some fish-remains have been found in many localities and sometimes in considerable abundance, both in the killas and in certain associated beds of limestone. These organisms serve to show that the rocks containing them are of Devonian age, or possibly lower carboniferous, but some of them may perhaps be upper silurian.

Mineral Lodes.—The granite and slate rocks, especially near their junctions, are traversed by great numbers of mineral veins containing the ores of tin, copper, lead, iron, and occasionally other metals; and also by many veins that contain only quartz or clay. These veins are illustrated in Fig. 4, Plate 29, which is a plan of the chief mineral veins in Wheal Seton and the adjoining mines, near Camborne. The veins yielding ore are termed by the miners "lodes," and those filled with quartz or "spar" are known as "cross-courses," while the clay veins are commonly called "flucans." These veins are further illustrated by the transverse section of the lodes in Fowey Consols copper mine near Par, shown in Fig. 5, Plate 30.

The lodes of tin and copper occur in both the granite and the slate, but seldom far from the junctions of the two rocks; the lodes of lead and iron not only occur in similar situations, but are still more frequently found at considerable distances from such junctions. Some lodes have copper ore only in the slate, and tin ore only in the granite; and at Botallack mine, it has been stated by Mr. Henwood, to whom the writer is indebted for many of the facts mentioned in this paper, that one of the lodes was found to pass three times from granite to slate, or the reverse, containing none but tin ore in the granite and none but copper ore in the slate. This is the well known tin and copper mine upon the coast near St. Just, the workings of which extend nearly half a mile under the sea; the Corpus Christi lode, in which this occurrence was met with, is about 100 fathoms east of the Crowns lode, along which

the section shown in Fig. 10, Plate 34, is taken; it runs nearly parallel to the junction of the granite and slate, and as this junction is very irregular, the lode passes alternately from the one formation to the other.

The different veins, cross-courses, &c., are plainly true fissure veins; at any rate they are so in the great majority of instances, and in many cases it is evident that the same fissure has been opened at many different times, as might reasonably be expected, because the fissures, whether partially filled up or not, would usually be lines of weakness. This is illustrated by the section in Fig. 12, Plate 36, showing the "combed" structure by no means uncommon in mineral veins or lodes. These veins are very frequently "lines of fault," especially the "cross-courses" or north-and-south quartz veins; and displacements of the rocks, causing "heaves" of the lodes at the points of intersection, are exceedingly common. The apparent displacement is usually horizontal, and sometimes extends to a distance of many fathoms; but it is evident that this appearance is produced by a vertical movement of rocks containing lodes which are inclined from the vertical, or have, to use a local term, a considerable amount of "underlie."

The mean directions* of the tin and copper lodes are found to differ in different parts of the district; but on the whole they bear, as shown on the plan, Fig. 4, Plate 29, nearly east and west, while those of lead and iron are more frequently north and south,

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* The mean directions of the lodes in the different parts of Cornwall have been given by Mr. Henwood as follows:—

St. Just . . .	35°	South of East and North of West.
St. Ives . . .	8°	
Gwinear, &c. . . .	2°	
Marazion . . .	1°	North of East and South of West.
Helston . . .	16°	
Camborne, &c. . . .	20°	
Redruth, &c. . . .	22°	
St. Agnes . . .	22°	
St. Austell . . .	13°	
Caradon . . .	18°	
Tavistock, &c. . . .	9°	

at any rate approximately. The greatest deviation from the mean east-and-west direction of the tin and copper lodes occurs in the St. Just district, where they bear as much as 35° south of east and north of west. Their average bearing throughout Cornwall is about 5° north of east and south of west; a range not materially different from that of the fundamental granite mass extending from Dartmoor to the Land's End.

Some of the lodes are nearly vertical, but they mostly incline or "underlie" more or less from the vertical in different directions. The mean dip of the lodes may be taken at about 70° from the horizontal or 20° from the vertical, having, as the miners express it, an underlie of about 2 feet per fathom. The dip or underlie of the east-and-west lodes is much more frequently towards than from the nearest granite mass. The average width of the lodes is about 4 feet. A transverse section is shown in Fig. 6, Plate 31, of the copper and tin lodes at Bull's shaft in Wheal Seton, near Camborne, and in Fig. 7 is a section of the same lodes at Tilly's shaft about 90 fathoms further west in the same mine. These sections illustrate the underlie of the lodes.

It should be noticed that the same lodes may within short distances vary a good deal in bearing, width, dip, and in the nature of their contents; an illustration of variation in bearing is shown in Fig. 8, Plate 32, which is a plan of the main lode in Wheal Seton, showing its position at successive depths from 80 to 140 fathoms. The lodes also frequently split or divide into branches, and these branches may or may not afterwards come together again. If a lode divides into branches, and these branches again unite, the included portion of "country" is called a "horse." A remarkable group of such lodes is seen in the section shown in Fig. 5, Plate 30, of the copper lodes in the celebrated Fowey Consols mine, which also well illustrates variations of underlie; and at H is seen a "horse" of killas included within two branches of a lode.

An examination of the displacements of the different veins, at the points where they are intersected by other cross veins and by each other, has shown that some are much more ancient than

others. They were divided by the late Mr. Carne, so long ago as 1822, into eight groups according to their relative ages; and more recent observations have by no means invalidated his conclusions. Of these different sets of fissures the oldest were probably formed in late carboniferous or early permian times; the newest may possibly be post-glacial.

Both the granite and the slate are much traversed by so-called "igneous" rocks of an intrusive character; which are chiefly broad dykes of porphyry or irregular masses of trap rock. The quartziferous porphyries, locally termed "elvans," predominate in the mining districts within a moderate distance from the granite, while the greenstones or "diorites" are most frequent at greater distances from the fundamental rock; both occur together however in several of the mines about Camborne, as in Wheal Seton workings shown in Fig. 9, Plate 33. In this section the parts which were rich in copper ore are shaded lighter, and the change to tin ore as the depth is increased is indicated by the darker shade; the present depth of Tilly's shaft is 210 fathoms below adit, the ground being still killas at the bottom of the shaft; from the 150 to the 190 fathom level the lode contains chiefly copper ore with some tin, and below the 190 fathom level chiefly tin with some copper. The elvans, like granite, consist of quartz, felspar, and mica; differing from granite more in the mechanical condition of their constituents than in their mineral composition. They consist of a non-crystalline felspathic base, through which, together or separately, are frequently and irregularly interspersed distinct crystals of felspar, crystals or nodular granules of quartz, and flakes of mica. The greenstones seem sometimes to improve, sometimes to deteriorate, the deposits of ore in their vicinity; but the influence of the elvans is often highly beneficial. They occasionally appear to traverse the lodes, but usually the lodes pass through them, showing the lodes to be of more recent formation. The majority of the elvan courses have a general east-and-west direction; many have been traced for eight, ten, or twelve miles in length. They have a considerable underlie, like the lodes, but their width is many times greater, many elvans of

from 15 to 40 fathoms in width being known, while the average width of the lodes is only about 4 feet.

Tin and Copper Mines.—In consequence of the great inclination of the lodes from the horizontal, averaging 70°, the mode of working is necessarily quite different from that adopted in the case of beds that are inclined but little from the horizontal, such as the beds of iron ore and coal in the centre and north of England. The difference is indeed extreme in all the important points: the ores being in irregular, comparatively thin, and nearly vertical veins, instead of the regular, thick, and nearly horizontal beds of coal and iron ore in other districts. Again the material composing the veins of tin, copper, lead, and other ores, contains in general but a very small proportion of saleable ore, seldom so much as 1 per cent. of the whole mass in any given mine; while that portion which is raised to the surface rarely yields more than 2 to 4 per cent. of saleable produce, instead of the 25 to 60 per cent. of iron ore or coal in the other districts. The iron lodes of Cornwall and Devon are however much richer than the lodes of tin, copper, and lead: from 80 to 95 per cent. of the material raised being merchantable ore.

With but few modifications the following mode of working is universally adopted throughout the Cornwall district, and indeed elsewhere for similar deposits of ore. The position of the lode at the surface, its bearing and underlie, having been determined as accurately as possible, one or more shafts are commenced at suitable points. These are frequently sunk on that side of the lode towards which the underlie is; or they may be sunk between two lodes so as to serve for working both of them. The shafts are almost invariably rectangular in plan, and the first portion at least is sunk vertically, although when the lode is reached the shaft is very frequently continued upon it and following its underlie, as shown in the sections of Bull's and Tilly's shafts in Figs. 6 and 7, Plate 31. Frequently however the more modern shafts are sunk vertically for their whole depth. A very few, such as the Diagonal Shaft at Botallack mine, are carried down inclined throughout, following the course of the lode, as shown in the section of the workings on the

Crowns lode, Fig. 10, Plate 34. The diagonal shaft is driven 6 feet square through very hard hornblende slate at an inclination of $32\frac{1}{2}°$ to the horizon, or 1 in 1·57, the length being 345 fathoms to reach the 180 fathom level; it was commenced about 1858 and occupied four years in sinking, the object being to get to the rich "shoots" of ore without the expense of a number of long levels, the 150 and 180 fathom levels being respectively about 210 and 250 fathoms long. The expectation was that the rich parts of the lode would be met with in an inclined direction approximately parallel to the junction of the granite and killas, the line of which is shown in Fig. 10; this expectation has only been partially realised. The lode yielded £50,000 worth of ore above the 150 fathom level, of which £24,000 worth was raised in one year between the 85 and 115 fathom levels.

Whenever the inclination of the surface is considerable, a tunnel or "adit" is driven, as shown in the sections Figs. 3, 5, 6, 7, and 9, from the nearest valley or watercourse available, directly into the hill in which the lode is situated, so that all the water from the portion of the mine above that level may drain away by the adit. This serves also to carry away the water pumped from the deeper levels, which would otherwise have to be raised to the surface. In some tin mines where the water is required for the purposes of dressing the ore, the adit is of but little importance; but in others where there is an abundant supply of surface water for dressing purposes, and in copper mines where this is not so much required, the saving effected by the adit is often very great. Sometimes one large adit is made to carry away the water from many mines by means of branches, and one such adit recently completed in Germany is upwards of 14 miles long. Even this is eclipsed by the Great County Adit of Cornwall which is shown in the plan, Fig. 11, Plate 35, drawn to a scale of $1\frac{1}{2}$ inches per mile, and is situated near Redruth at the point B on the map, Fig. 1. This adit with its branches is upwards of 30 miles in length, and was made by Mr. Williams, of Scorrier, near Redruth, about the middle of the last century. It is at present of comparatively little importance, many of the principal mines for which it was constructed being worked out and abandoned;

but some few years ago it drained an area of 5550 acres, and discharged on an average no less than 1450 cubic feet of water per minute. From this water in the years 1864 to 1867 about 23 tons of fine copper was annually obtained by precipitation upon wrought iron. The adit discharges into the Carnon stream, the outfall of which is into Restronguet Creek. The mouth of the adit is 39 feet above high water, and the fall along its course from the distant portions to the mouth ranges from about 50 to 80 feet. The figures inserted upon the plan, Fig. 11, give the depth of the adit below the surface of the ground in fathoms, showing the depth that is unwatered by the adit in the different mines. The plan shows the position of many lodes which occur in both the granite and the killas; it also shows the frequent "heaves" of the lodes by the cross-courses.

As an illustration of the large quantities of water which have occasionally to be pumped out of the mines, even when not very extensive, it may be mentioned that at Mellanear mine, near Hayle, in one month from 19th April in the present year, and indeed for many months previously, the average quantity of water raised was no less than 1162 gallons per minute. For pumping purposes the engines are almost always of the single-acting "Cornish" type, of which many fine examples are to be seen within the Cornwall district. Although the duty of these engines has from various causes greatly fallen off within the last thirty years, their performance will still as a whole compare favourably with that of the engines of any other mining districts. At Mellanear for example, during the period above referred to, and although the engine was working at the unusually high rate of 12·2 strokes per minute for the whole month, including all stoppages, the average duty was no less than 49 million ft.-lbs. per cwt. of coal consumed. During the same month the duty of the 85 inch engine at Dolcoath, working 4·4 strokes per minute, was 65·6 millions. Each of these engines is supplied by four Cornish boilers, and steam at from 40 to 45 lbs. pressure per square inch.

The adit is sometimes driven on the course of the lode, in which case it constitutes a true "level;" and sometimes in a

transverse direction, when it would be more properly termed a "cross-cut." Other levels are then usually driven at distances of 10 fathoms or 60 feet apart, both above and below the adit; and these are sometimes driven on the lode, sometimes by its side, but always following its course. The underlie of the lode makes these levels appear in the plan as so many parallel or approximately parallel lines; but in the vertical longitudinal section they will of course appear as parallel lines one beneath another. As the levels become extended to great distances from the shafts, smaller shafts called "winzes" are sunk from one to another as shown in the section, Fig. 9, Plate 33, not only for the purpose of ascertaining the value of the lode, but also for ventilation. When the shaft is not sunk "on the lode," that is, following the direction of the lode, the communication with the various levels is effected by cross-cuts; and similar cross-cuts are also frequently driven from one lode to another.

The lodes in some parts contain very little of the ores sought for, being filled with veinstuff of little or no value, or they may be so thin as not to pay for working; but at other times they swell out and rich bunches of ore are found. In some mines the lodes which were rich at first have become poor for hundreds of feet in depth, and have yet proved to be rich at still greater depths. This has been pretty generally the case with the mines around Redruth and Camborne, Dolcoath mine being a notable example. This was formerly one of the richest copper mines in the world, but from about the 130 to the 180 fathom level below the adit it was found to be exceedingly poor; below the latter level however it has yielded very large quantities of tin, and the present bottom level, which is 314 fathoms below the adit and nearly 350 fathoms from the surface, is very rich indeed. Where the lodes are rich enough to make it worth while, the ore is often dug out completely, as shown in the section of Wheal Seton, Fig. 9, and Botallack, Fig. 10. Frequently however in large mines some of the richer portions are left as reserves, to be worked should the bottom of the mine become poor, and to pay the expenses of further explorations.

The miners are usually paid for sinking shafts or winzes and for driving levels at a certain rate per lineal fathom; this is called "tutwork." Common dimensions are:—

		Feet.		Feet.
Engine shafts	from	8×6	to	12×9
Air shafts and Winzes	,,	4×2	,,	6×4
Levels	,,	$6\frac{1}{2} \times 2\frac{1}{2}$	,,	7×5

Levels are frequently made somewhat larger at bottom than at top. Timbering, when required by the nature of the ground, is frequently done by the miner as part of his bargain, and the excavated material is drawn to surface at his cost. Sometimes however the timbering is done by special "timber-men," and the ground broken is raised to surface on "owner's account." The prices of sinking or driving vary much according to the nature of the ground, the depth from surface, the area of cross section, and many other particulars; but the following prices, many of which have been recently paid within the writer's knowledge, will give some general idea of the labour cost of such works. For greater convenience the prices have been calculated to cubic fathoms instead of lineal; and they are subject to deductions for all such materials as powder, candles, and tools supplied to the men from the stores of the mine.

For sinking shafts in soft killas, or clay ground.

Near the surface, say less than 20 fms. depth	£2 to £3	per cubic fathom.
Below about 20 fathoms	£3 to £4	,,

For sinking shafts in compact killas, or "pick and gad" ground.

Near the surface	£4 to £6	per cubic fathom.
Below about 20 fathoms	£5 to £8	,,

For sinking shafts in "fair blasting ground."

Near the surface	£6 to £20	per cubic fathom.
Below about 20 fathoms	£10 to £30	,,

Levels perhaps one third cheaper for non-blasting and half cheaper for blasting ground.

In extreme cases much higher prices have been paid; thus at East Pool mine near Redruth as much as £37 per cubic fathom has been paid for sinking in granite, and £24 per cubic fathom for cross-cutting in the same rock. At North Pool mine £51 per cubic fathom has been paid for driving a level in greenstone, and the same price has been paid at Heytor Vale iron mine near

Bovey Tracey in Devon. A portion of a shaft in greenstone at North Roskear mine near Camborne is said to have cost nearly £500 per fathom of depth, the dimensions of the shaft being 12 feet × 8 feet, equivalent to £187 per cubic fathom. To avoid sending too much of the veinstuff or waste to the surface with the ore, the parts of the lode between the levels are often removed by "tributers," who are paid a certain percentage upon the value of the ore raised, the rate varying from a few pence to 15*s.* or 16*s.* in the £; so that it is to their interest to keep the waste or "deads" separate from the ore. When the lode is very rich however, or very even in quality throughout, it is usually removed by "tutworkers," or else by "stopers" who are paid at a fixed rate per ton; a common price for stoping in blasting ground is 3*s.* per ton.

In metal mines, the lode and the containing rock called "country" are either or both of them very frequently so hard that it is necessary to blast with gunpowder or some other explosive. Although dynamite and gun-cotton have been used in some of the Cornish mines with good effect, yet as a general rule gunpowder is most used, principally as the writer believes on account of its lower first cost. He is not aware that gun-cotton is made use of in any Cornish mine at the present moment except Dolcoath; but dynamite is greatly valued, especially for wet holes, by those who have had experience of its use, notwithstanding the undeniable disadvantage of its very poisonous products of combustion. The use of some form of safety fuse in blasting is, the writer believes, a universal practice.

For the means of conveyance in the mines, trams are every year becoming more common, upon which the stuff is conveyed in tram-wagons pushed by hand; but there are still some mines in which all the stuff is conveyed along the levels in wheel-barrows. When it reaches the shaft, it is loaded into "kibbles" or into "skips," and raised to the surface. The kibbles are iron buckets hanging free in the shaft, and the skips rectangular boxes having rollers running upon guide-rods fixed in the shaft; the latter plan being used more particularly for working in inclined shafts. In shallow mines the ores are raised by means of a

hand-windlass or tackle, and in deeper ones by a horse-whim or steam engine. As a rule the machinery for raising the ore is greatly inferior to that used for draining the mines. The stuff is drawn to surface in quantities varying from 1 cwt. to 1 ton, and with a very slow rate of motion. This is in part owing to the smallness and irregularity of the shafts in many of the oldest mines, and in part to the fact that the winding engines are very frequently used in addition for stamping purposes. In the larger mines the use of wire rope for drawing purposes is now almost universal.

The ventilation of the mines is almost always effected by natural means, and is now rarely very defective, except in those places in which exploratory works are being proceeded with. In some cases however some artificial means of ventilation on a large scale is very much to be desired; but the absence of any combustible emanations renders this less a matter of absolute necessity than in coal mines. Lamps are unknown in the Cornish mines, the work being invariably carried on by the somewhat expensive aid of tallow candles; a lump of clay serves as a candlestick to attach the candle either to the hat-cap of the miner, or to the side of the level in which he is at work.

The miners usually go to and from their work by means of ladders placed almost vertically; occasionally they are raised and lowered by means of the skip used for raising ore, but in a few of the larger mines a peculiar contrivance called the "man-engine" is now employed. This consists of a vertical beam of wood, called the "rod," which is made to move alternately up and down through a space of twelve feet by means of a steam engine or water wheel. On the rod steps of wood about a foot square are fixed twelve feet apart, upon which the men stand while the rod is in motion, holding on by iron loops fixed on the rod for that purpose. When the rod stops at top and bottom of the stroke, its steps are level with little platforms called "sollars," which are fixed in the sides of the shaft. By standing on the steps of the rod during its upward motion only, and on the sollars while it moves downwards, the men are raised to the surface by successive lifts of twelve feet

or two fathoms, without any labour on their part beyond stepping from the rod to the sollars and back again. As many men may thus be brought up from their work at one time as there are steps on the rod, and as the sollars are fixed on both sides of the shaft, an equal number of men may be carried down at the same time, each descending man stepping on the rod as the ascending man steps off, and *vice versâ*. The man-engine is so great an advantage to all concerned, that it would soon become generally used, were it not that most of the shafts in old mines are too narrow and also too crooked to admit of its introduction; the cost of the rod itself and of its fittings is also very considerable.

Quantities and Values of the Ores.—Tin Ore.—The total value of the tin ore raised in Cornwall and West Devon has increased in six years from £667,999 in 1866 to £1,068,733 in 1871, the year 1866 having been one of great depression in the metal trade. The weight and value of the tin ore raised in the several years were as follows:—

1866 . . .	13,785 tons	£667,999
1867 . . .	11,066 „	549,375
1868 . . .	11,584 „	641,137
1869 . . .	13,883 „	889,378
1870 . . .	15,234 „	1,002,357
1871 . . .	16,898 „	1,068,733
1872 (estimated) .	14,300 „	1,000,000

Copper Ore.—The annual value of the copper ore raised in the district has diminished from £547,689 in 1866 to £316,213 in 1871, owing to the exhaustion of some of the mines, and the closing of others in consequence of the lowering of prices which has been caused by the large supplies of foreign copper. The weight and value of the copper ores raised in the same six years were as follows:—

1866 . . .	125,679 tons	£547,689
1867 . . .	121,815 „	554,029
1868 . . .	103,199 „	430,749
1869 . . .	90,227 „	374,612
1870 . . .	74,367 „	292,122
1871 . . .	67,543 „	316,213
1872 (estimated) .	66,000 „	315,000

Within these years the average price of fine copper has been only about £79, while for the ten years previous it was £104.

Lead Ore.—The lead ore raised in the district averages 8000 to 9000 tons annually, and it is unusually rich in silver, yielding about 35 oz. of silver per ton of ore, while the average yield of the lead ores from the rest of the United Kingdom is only about 8 oz. of silver per ton. The lead, as already mentioned, occurs mostly in veins bearing nearly north and south; and, unlike those of tin and copper, some of the best lead deposits have occurred at considerable distances from any of the granite masses. The lodes vary in bearing, underlie, width, and productiveness, in different parts of their course, in a manner precisely resembling the tin and copper lodes, and they are worked in exactly the same way. The ore is almost exclusively of the kind known as galena or lead glance, which is sulphide of lead.

Iron Ores.—The iron ores of the district are only now beginning to be worked to any considerable extent, as hitherto the low price of iron and the small facilities for local carriage have prevented their due development. The recent great advances in the price of iron have however directed attention to the valuable iron lodes of this district, which contain many millions of tons of rich hæmatite ores of great purity, together with smaller quantities of magnetic and spathose ores. Many new lodes have been discovered, and considerable sums of money have been and are being spent in providing facilities for the local transit of the ore by constructing branch railways; and it may fairly be expected that the marked increase within the last two years in the quantity of ore raised will be maintained, and subsequently much exceeded. One of the lodes, the working of which has been recently recommenced under very favourable auspices, is known as the Great Perran Lode, shown in the plan, Fig. 1, Plate 22. It is known to extend from the coast near Perranporth several miles inland, and is in places 30, 60, and even 100 feet wide; it is at present being worked in open cutting at several points. Many other lodes, some containing ore of even greater purity, are known to extend for several miles in length, varying in width from 3 to

15 feet; and several have been worked to depths of 20 to 60 fathoms, and the ore found to hold in depth.

The annual value of the iron ores raised in the two counties is as yet not very great. The great depression in tin and copper mining in the year 1866 led to a considerable output of iron ore from the "backs" of the iron lodes, that is, near the surface of the ground; but very little capital was then expended in opening up the lodes in depth. As the prices of tin and copper improved, iron mining was again abandoned for the time, but the improved prices of iron since 1870 have put iron mining upon a better footing. The following are the quantities and values of the iron ores raised in the seven years from 1866, the exceptional year, to 1872, together with the average prices of Welsh pig iron for the several years:—

			Average price of Welsh pig iron per ton. £ s. d.
1866	59,354 tons	£19,291	4 2 6 (1866–1870)
1867	16,638 „	5,182	
1868	19,488 „	6,128	
1869	11,723 „	3,941	
1870	21,407 „	6,703	
1871	36,072 „	17,605	4 6 7
1872 (estimated)	45,000 „	25,000	6 12 0

These quantities are very small as compared with the total production of iron ore in the United Kingdom, owing to the small scale of the workings and other exceptional reasons; but the deposits are large and numerous, and when the facilities for local transit are once completed the annual production cannot fail to be many times multiplied. Even though the price of ore may fall, as is not unlikely, and notwithstanding the recent great advances in the cost of labour and materials, the centre of Cornwall must become famous for iron ore, as it has become within the last half century for china-clay.

China-Clay.—The deposits from which china-clay and china-stone are obtained are very irregular in their occurrence. They seem to be portions of the various granite masses decomposed *in sitû*; and they often cover a considerable extent of surface. Their extent in depth is unknown, but at Beam mine and also at Rocks mine,

both near St. Austell, china-clay was found at a depth considerably exceeding 60 fathoms from the surface. Their situation is frequently indicated by slight depressions of the surface, and they are often crossed by lodes and branches yielding tin ore of a very pure kind. At Carclaze, near St. Austell, one of the largest of these deposits was worked until the present century simply as a tin mine carried on by open cutting, for the sake of small veins of good tin ore that intersected it, and the china-clay removed in getting the tin ore was thrown away, its value not being known; this excavation for china-clay now extends to a depth of 25 fathoms, a length of a quarter of a mile, and an area of about 5 acres. Many similar but smaller excavations are to be seen in the same neighbourhood.

Some portions of these decomposed masses, of rather peculiar mineralogical and mechanical character, are quarried and sold without preparation as china-stone, which is used in some of the potteries, being ground and mixed with different kinds of clay. In those portions from which the china-clay is obtained, the felspar of the original granite is seen to have existed in crystals of considerable size; and these retain their form and position, but are completely altered to kaolin or china-clay by a kind of pseudomorphic action. To make this clay marketable it is only necessary to break down the soft decomposed rock, and direct a stream of water over it, when this water becomes at once thick with the suspended particles of the clay, and the mica with which it is always accompanied in considerable quantity. The milky stream is then guided into narrow channels called "micas," in which the current receives a check, and the heavier particles of mica are deposited. The clay is finally settled in large tanks or "pans," and afterwards dried, often by exposure to the air, but mostly by means of heated flues or "drys," over which the partially consolidated clay is placed for the purpose. As soon as the clay is dry it is ready for sale, part being carted at once to the shipping ports in a loose state, and part packed into barrels or bags for exportation. It is much used for the finer kinds of pottery, but large quantities are used for

paper-making, bleaching, and also, it is said, for the adulteration of flour.

The deposits of china-clay occur in connection with each of the separate granite masses, but the most important of those at present in work are situated near St. Austell in Cornwall, and at Lee Moor in Devon. Besides the china-clay and china-stone, considerable quantities of pipe-clay and ordinary potter's clay are raised annually at Bovey Tracey and other places in Devon, and at St. Agnes in Cornwall. In the year 1871 the following total quantities were shipped:—

Cornwall.	China-clay	125,000	tons.
,,	China-stone	33,000	,,
,,	St. Agnes clay (estimated) . .	1,000	,,
Devon.	China-clay	19,000	,,
,,	Pipe-clay and Potter's clay . .	47,639	,,
	Total	225,639	tons.

Very recently considerable quantities of the refuse of the china-clay works have been worked up into most excellent fire-bricks; thus laying the foundation of another industry.

Other Minerals.—In addition to the mineral products that have been mentioned, considerable quantities of pyrites (sulphide of iron), gossan (the upper decomposed part of a lode, usually containing oxide of iron), and other minerals are annually raised in Cornwall and Devon, including more than 4000 tons of arsenic having a value of about £16,000. Large quantities of granite and slate are also supplied; and in Devon, limestone and building stones of different kinds. Altogether there would probably not be much error in estimating the value of the mineral produce of the district at nearly £2,000,000 per annum, tin ore alone producing about one half this amount, and copper ore and china-clay each something more than one fourth of the remainder.

Mr. Collins exhibited and described a number of specimens of the different minerals referred to in the paper. Among those illustrating the granitic rocks of the district was an excellent specimen of what might be called perfect granite, such as was obtained from the Lamorna granite quarries near Penzance, which showed each of the three component minerals distinctly and in the most perfect form: the quartz was perfectly crystallised, and the felspar and mica were quite in their normal crystalline condition.

In the specimens of elvan it would be seen that, although composed of the same three minerals, these were by no means so distinct; and though some specimens contained very well defined crystals of felspar, which seemed even more perfect than those in the granite, yet most of the rocks of this kind might be described rather as a mass of uncrystallised paste. The most commonly crystallised portion of the elvan was the felspar, but sometimes elvan contained crystals of quartz and also of mica.

Another specimen was what miners called "secondary granite;" not meaning that it had been formed at a subsequent period to the other granite, but only that it had some appearance of a changed character. The minerals that composed it seemed to have run a little into one another, giving it somewhat the appearance of a metamorphic rock. This kind of granite was more frequently found in connection with the metalliferous mineral districts of Cornwall than elsewhere. The specimen exhibited was from East Pool mine, lying on the north side of Carn Brea Hill.

Another specimen showed a vein of granite in the midst of killas rock. This sort of structure could be seen better on the north-west side of St. Michael's Mount at low water than in any other part of the county, great numbers of granite veins being there seen to pass through the killas rock in all directions.

China-stone was also a kind of granite, but seemed to be a good deal altered, the felspar being in a very decomposed condition, and the quartz by no means so distinct as in pure granite. China-clay in its natural condition was very much the same as china-stone; but the decomposition seemed to have gone still further, the felspar being here completely changed into clay; and

nothing more was necessary for extracting the clay than the disintegration of the whole mass by water, by which the clay was carried away in suspension.

While the granites and elvans belonged to the plutonic class of rocks, the specimens of greenstones represented the class of rocks that were distinctly volcanic in their origin. Although rocks of this character were much more abundant in the parts of the county away from the granite, being particularly developed in the extensive Lizard district south of Helston, and in the north of Cornwall from Newquay to Tintagel, yet there were many instances of the occurrence of greenstones in two or three of the more important metalliferous districts.

The specimens of tinstone containing wolfram were of considerable interest, on account of the close resemblance of wolfram to tin ore in specific gravity and general character. The processes now in use for the mechanical separation of the tin ore from its matrix failed altogether to separate the wolfram, on account of its specific gravity being so nearly identical with that of tin ore, and the only means at present known of effecting the separation was by a chemical process. Fortunately for tin miners it was only in a few mines that the wolfram occurred in large quantities; but where it did occur, it seriously reduced the value of the tin ore.

Another specimen was of much interest as illustrating the distinct combed structure so commonly met with in metalliferous lodes; it consisted of a mass of quartz containing veins of zinc blende deposited in successive formations. This was a somewhat less perfect specimen than many that were met with, the best specimens being very difficult to keep together, as the perfect combs fell apart so readily when disturbed in breaking the stones from the lode.

The specimens of killas, or altered clay-slates of the district, were of great importance, illustrating the three different kinds that were met with. The first, from East Pool mine, showed the sort of killas that occurred in the immediate neighbourhood of tin or copper lodes; the second kind was found in districts devoid of metalliferous veins; and the third was from an iron district, not far from a distinctly marked iron lode.

The stones of copper ore served to illustrate very well what had been said in the paper about the small comparative quantity of ore contained in the lodes of Cornwall. These specimens would certainly make a very good lode if they ran to a width of as much as about 4 feet; but in the actual lodes of that width the case was very different, the ore being considerably less in quantity than the waste. Even when the whole width of a lode was made up of yellow ore, which was the most abundant ore of copper and contained about 34 per cent. of metallic copper, it occurred that the lode would sometimes shrink to a few inches in width, and sometimes to a mere string, although it was also true that it would sometimes swell out and become very wide and rich for a time. The latter condition however was exceptional; and when allowance was made for the waste, it would be seen that as a rule the percentage of metal contained in the lodes must be very small.

This was still more true with regard to tin, the tinstuff raised from a lode seldom bearing any very large proportion to what was left behind as waste. Few of the lodes from which tin was now being raised were producing more than 1 per cent. of black tin on the average from all the stuff drawn to surface; and of this 1 per cent. of black tin, not more than seven tenths (0·7 per cent. of the whole) on an average was white metal or metallic tin. In certain places indeed, where tin lodes were now being worked at the surface in Cornwall, and where consequently no expenses had to be incurred in raising the stuff to the surface, a fair profit was even being realised by extracting from each ton of stuff as little as 3 lbs. of black tin, worth altogether at the present price of tin about 2*s.*; this was equivalent to a proportion of little over 1-8th per cent., or 1 ton of black tin extracted from about 750 tons of stuff.

Mr. Richard Taylor said that, having a pretty intimate knowledge of the Cornwall mining district, he did not think a clearer and more accurate description could have been given of the general mineralogical character of the county and the distribution of the various minerals than that furnished in the paper now read. The great fact arrived at from the experience of Cornish mining was

the accumulation of valuable metallic minerals at and around the junctions of the granite and the killas. This was true with regard both to copper and tin; and a particularly good example was afforded by the rich metalliferous district known as the Camborne mining district. The great depth to which the mines of Dolcoath, Tincroft, Cook's Kitchen, and others, had now been worked, had made known in later years the very curious fact mentioned in the paper with regard to the ores of copper and tin. Originally worked, as these mines were, principally for copper, there was always some tin, even in the upper portions of the lodes which were very rich in copper. During the earlier part of his own practical acquaintance with Cornish mining, which extended forty-three years back, Dolcoath and the neighbouring mines, though principally yielding copper, had occasionally been raising tin. But as greater depths were attained, it had been found that the quantity of copper diminished while the quantity of tin increased. The deepest part of Dolcoath was now nearly 350 fathoms or 700 yards below the surface, and was still rich in tin. There was indeed no practical limit, he believed, to the depth to which a mine might be worked; and some persons were sanguine enough to hold that the deeper they went, the richer would all the tin mines be. Whether this were the fact or not, there was certainly no practical impediment in the way of going deeper than the present deepest mines; difficulties of course there would be, but these would be merely mechanical. One difficulty met with in working copper mines in other parts of the county, and one which had been found extremely hard to overcome, had been the great heat that was encountered in going to great depths. In the working of the Consolidated and the United Mines in Gwennap, the heat in the former was very considerable in the lower levels at the depth of about 300 fathoms from surface; and in the United mines, which were on parallel lodes at no great distance from the Consolidated, a hot spring of water was met with in the bottom level at about 250 fathoms depth, having a temperature of as much as 115° Fahr.; the rock also was so hot that the men could not lean against it even with the protection of their thick miner's clothing. This

had proved a very serious difficulty, the heat being so great that none but very young men, scarcely any above twenty-one years of age, could possibly work in that level, and those who did work there very often fainted. The remedy adopted had been to carry down a stream of cold water in pipes, and the miners when they felt overcome by the heat would run out of the level and throw themselves down where the cold water could run over them; still there was a very great difficulty in carrying the work on. This and many other circumstances connected with the pumping, the difficulty of securing efficient ventilation, and the low price of copper, which rendered the raising of it under such conditions no longer remunerative, at length put an end to the working of those mines. In the mines of the Gwennap district tin was found more or less throughout the whole working, quite up to the surface in many of the lodes; but in no instance was there that great increase of tin in depth which had been the case in the Camborne district. Unfortunately the deep mines in Gwennap had now ceased to be worked, and were all under water, and apparently likely to remain so; but perhaps at some future time it might be tried whether the lodes in that district became richer in tin at the same depths at which the increase in quantity of tin had been met with elsewhere.

The lead mines of the county, the importance of which had been alluded to in the paper, had perhaps not received hitherto so much attention as they deserved, on account of their being a good deal scattered and somewhat remote from the principal old mining districts. There had been, and were still, many very valuable lead mines in Cornwall. In the district lying nearly due north of Truro there had been originally the famous Shepherd's mine, Wheal Rose, and subsequently East Wheal Rose, which had been so very rich for many years; and a little to the east lay the Chiverton district, where there were still very rich mines, rich not merely in lead, but in lead ore containing a very large proportion of silver. These mines were in rocks of a different lithological character from the killas of the copper and tin districts, but the same killas ran in and out very near them, and was found more or less in almost every

part of the county. There were lead mines also to the south-west of Helston and to the south of Truro; and in the eastern part of the county was the rich lead district of Liskeard, not far from which was Herodsfoot mine, so remarkably rich in the amount of silver contained in its ores.

The importance of the Cornish iron mines had been very properly referred to, because there was some difficulty at the present time in getting a supply of the ores requisite for the manufacture of Bessemer steel. Large quantities of these ores were undoubtedly to be obtained from Spain, particularly from the great mines of Somorostro in the neighbourhood of Bilbao; but the present disturbed political state of that country rendered it very doubtful whether it would be possible to draw the required supplies from thence for some years to come. There were many extensive iron mines in other parts of Spain, especially on the south coast, and also others of importance in Algeria; but they were attended at present by the drawback of a heavy cost of transport. In England the chief supplies of this class of iron ore had hitherto come from the red hæmatite of Cumberland and Lancashire; the red ore found in Cornwall was not as good as that of Cumberland, and the quantity available was not large. Brown hæmatite however was more plentiful, many mines of it had been worked in the central and northern parts of the county, and as much as 30,000 tons had been shipped in one year from the Restormel mine near Lostwithiel, and in many years its produce had exceeded 25,000 tons. That mine enjoyed the advantage of being near the quays on the navigable river Fowey, which terminated in the deep-water harbour of the same name. A period of greater activity seemed now about to be entered upon with regard to the iron mines of Cornwall, which hitherto for the most part had had to contend with very inadequate means of transport. Moreover the brown hæmatites of Cornwall were said to be on the whole too silicious to be generally acceptable to ironmasters; if the ore were of the same value as copper ore and were treated in the same manner, this objection could be got rid of, because nothing was easier than to wash the brown hæmatite free from quartz, there being so great a difference between its

specific gravity and that of quartz. The great cost of transport was undoubtedly what had hitherto militated so much against the success of the iron mines of the county. Vigorous efforts were now being made to remedy this defect, especially in regard to the Perran district; and he trusted the iron mines of that district would realise the hopes entertained of them, and would come to make up for the falling off in those of copper and tin.

With the china-clay and china-stone districts of the county, which had been accurately described in the paper, he had formerly been connected on behalf of the Duchy of Cornwall; they were very interesting indeed, and had recently given rise to legal arguments of great length as to whether china-clay was to be regarded as a mineral or not.

Mr. S. Harvey James, of Botallack, and Capt. James Bennetts, of Spearn Moor, concurred in expressing their high opinion of the value and accuracy of the paper that had been read.

Mr. Collins remarked that, with regard to the high temperature encountered in the United Mines in Gwennap, it might be suggested that this had perhaps not been quite an unmixed evil; for, considering the great depth of the mine, and the fact that the shafts, like those of nearly all the old mines, were very narrow and crooked, it seemed that, however unpleasant the high temperature was, yet in the absence of any special provision for ventilation, had it not been for the heat reducing the specific gravity of the air in the bottom of the mine, and thereby maintaining a constant current of air through the workings, the ventilation must have been so bad as to prevent the mine being worked at all.

With regard to the lead mines, he agreed in thinking that they had not received proper attention in consequence of lying away from the principal Cornish mining centres; and in Cornwall, as elsewhere, the attention paid to any district and the working or neglect of its mines had depended a great deal upon the means of transit, in which respect as in some others Cornwall was a good deal behind some other parts of England. Had this not been so,

the county generally would have been in a far better condition as regarded many matters connected with mining interests than it was at present.

With reference to the silicious nature of the Cornish iron ores, this was, as had been pointed out, simply a matter of cleaning the ores. Much of the iron ore that had hitherto been sent out of the county had been obtained chiefly from the backs of the iron lodes, where it was almost always highly silicious and mixed with many impurities; and it had been raised principally by farmers, or by miners who were pretty well acquainted with copper and tin ores, but knew scarcely anything about iron ore, and had no machinery for cleaning it. The ore had consequently been sent away in bulk, without regard to its quality, all mineral of a brown colour that did not contain tin or copper being supposed to be iron ore; and this negligence had brought the Cornish iron ores into bad repute. They could however be cleaned with comparative ease, as had been stated; and he knew of persons who would undertake to clean most completely any quantity of silicious brown hæmatite at one shilling per ton, increasing the value of the cleaned ore by at least 3*s*. per ton, and leaving a very good profit on the cleaning. The ore would be crushed down by a Blake's stone-breaker into pieces of $\frac{5}{8}$ inch or $\frac{1}{2}$ inch size or even smaller, and then washed by self-acting jigging machines. By this means therefore it would be seen that the objection of the silicious character of the ore was one which could be very easily got over.

Mr. W. Husband enquired whether any explanation could be given of the combed structure met with in metalliferous lodes.

Mr. Collins said the prevalent opinion among geologists was that in such cases the "country," or rock containing the lode, had originally been fractured by an earthquake or some other cause, so as to produce a fissure which remained unclosed; and upon the walls of this open fissure, probably from water continually trickling through it, were gradually formed the crystallised deposits of mineral matter, presenting the appearance of the combed structure. Eventually the fissure would in this way be filled, the deposits on either wall increasing until they met in the centre.

As a fissure thus filled would not be as strong as the solid rock on either side, any recurrence of the disturbing force that had in the first instance produced the fissure might be expected to open it again, and a new process of deposition would then be commenced. With each reopening and refilling of the fissure a new pair of combs would be formed, the last or centre deposit being the only single one. The successive openings of the fissures and the successive deposits of fresh mineral matter would thus readily account for the production of a formation resembling the combed structure; and this view was further borne out by the fact that the adjoining accumulations of deposit in any fissure were seldom of the same material. For instance, the outermost pair of combs, forming the walls of the lode, might be of quartz or of yellow copper ore, the next pair of zinc blende or of lead, the next of quartz, and the next of carbonate of lime or sulphate of barytes or some analogous mineral. Generally, though not always, one side of the combed structure corresponded with the other, not always in thickness, but in the nature of the minerals deposited, the combs being in pairs on each side of the centre of the fissure; and accordingly in any lode containing a deposit of two different minerals, one of them generally occurred on both sides of the lode. The example of combed structure represented in the drawing (Fig. 12, Plate 36) illustrated a somewhat different mode of formation, in which distinct fissures had been opened at C, D, E, F, G, and H; but there was nothing to show in what order these had been opened, except that the latest was in all probability at E, as indicated by the large central deposit of copper ore in that part of the lode.

Mr. W. Husband considered this explanation of the origin of the combed structure in lodes was perfectly clear; but there were also a great many cases where the lodes swelled out into "vughs" or cavities, and he enquired whether it was supposed that these openings had continued to exist from the time when the lode was in process of formation.

Mr. Collins thought the cavities met with in lodes were even now in process of filling, and that the reason they were found

only partly filled was that the filling process had not continued long enough. It had been proved by Bischoff, the celebrated German chemist, that all water percolating through the crust of the earth contained mineral matters; and Mr. John Arthur Phillips had found from an extensive examination of the water in Cornwall that even the most pellucid water contained a certain amount of mineral matter, whilst some of the Cornish springs contained a very large quantity. It was then easy to suppose that such water trickling through a fissure would gradually fill it up by depositing the mineral matter on its walls. With regard to the original formation of these cavities in the lodes, he believed this might be accounted for by the supposition that the fissure which was in the first instance produced in the rock by an earthquake was an irregular one; then it was clear that if the rock on one side of the fissure should sink down, or the rock on the other side rise, such cavities would be produced in consequence of the irregularities of the fissure; and whether the movement took place vertically or laterally or obliquely, a similar result would be produced. The coalfields as well as the metalliferous districts afforded abundant examples of these heaves, throws, or dislocations.

Mr. Richard Taylor thought it might readily be believed that the combed structure in lodes was due to gradual incrustation upon the walls of a fissure, and that the original fissure had afterwards opened again, and fresh incrustations had taken place; and if there were any vertical or horizontal motion on either one side or the other, there would then naturally be cavities wider in some places than in others, owing to the irregular form of the sides. Some of these cavities that were met with were very large indeed; in the Lanestosa lead and zinc mines near Bilbao in Spain one of the shafts that was being sunk had recently holed suddenly into a cavity that was found to be as much as about 15 fathoms long, 2 fathoms wide, and 3 fathoms deep, the sides of which were encrusted with mineral deposit; and in the bottom were a great number of large blocks of calamine mixed with lead, which had fallen away from the roof and sides of the cavity since its formation. In the Consolidated Mines in Gwennap he remembered a very

large cavity being met with, which had originally existed at a much greater depth; but owing to the weakness of the lode the roof had continually fallen away, and filled it up for some 30 or 40 fathoms height with pieces of the lode, consisting chiefly of copper ore, so that at length there was this very large cavity in a part of the lode where originally there had doubtless been a large course of ore.

Mr. C. COCHRANE remarked, with regard to the washing of the Cornish brown hæmatite iron ore, that for blast-furnace purposes it would be a step in the wrong direction to crush the ore down so that it would go through a $\frac{5}{8}$ inch or $\frac{1}{2}$ inch mesh. Such a process would make it less suitable for smelting, as it was already of a very suitable size to go into the blast furnace just as it came from the mine; and what was wanted was to wash it free from silicious matter, without crushing it.

Mr. RICHARD TAYLOR observed that the mention of washing alone, in reference to the preparation of the Cornish iron ore for smelting, would be rather misleading, as the cleaning required for the purpose consisted not merely in washing away the sand and dirt which encrusted the ore and would render it unsuitable for smelting; a great deal of the ore had the silicious matter so intimately mixed with it that it was only by crushing that this could be separated from it, but he was aware that ore so treated would be unsuitable for many purposes in iron-making. He thought it would be interesting to know the particulars of the cost that had been named of one shilling per ton for cleaning the ore, as he should have doubted any profit being realised on so small a charge.

Mr. JEREMIAH HEAD remarked that finely ground iron ore was in common use as fettling for puddling furnaces, and the highest price was paid for it in that condition. With regard to the Perran iron lode, which had been stated to be as much as 60 feet wide in some places, he enquired whether the ore occurred in a manner similar to that in tin and copper lodes, or whether it was met with in pockets as in Cumberland, or in horizontal beds as in Cleveland; and also what was the percentage of metallic iron contained in the ore.

Mr. Collins replied that the Perran iron lode was a distinct lode, just like other metalliferous lodes, and there were not any pockets or beds of the ore in the county similar to those of Cumberland or Cleveland. In that particular lode the ore was said to be scarcely so good as was found in some other parts of Cornwall, although from his own knowledge he could say that much of it was very good indeed. There would be no difficulty whatever in supplying from the Cornish iron mines brown hæmatite yielding over 50 per cent. of iron, and red hæmatite yielding over 65 per cent. If the iron ore were unsuitable for blast furnaces when crushed down so small as was occasionally necessary for cleaning it, it was to be hoped that it might still be found available for some other processes of making iron; at any rate a very large quantity of similar ore was already being raised from many of the iron mines in the district, and met with a very ready sale. With regard to the cost of cleaning the ore, the result of actual experience had proved that this could be done for one shilling per ton at a good profit. Very hard tinstuff, harder than the iron ore, was being crushed by means of Blake's stone-breaking machine at 4*d.* per ton, and in larger quantities it could be done for less. Of the 1*s.* per ton for cleaning the iron ore, 4*d.* was apportioned for crushing, 6*d.* for washing, and 2*d.* was left for profit; and he was satisfied that 2*d.* per ton could safely be made as profit, if a plentiful supply of ore could be relied on for cleaning.

The Chairman considered they were greatly indebted to the author of the paper for the comprehensive manner in which he had introduced a subject which to many of the members was a new one, and for the large amount of information which he had given upon it; the paper had proved a most interesting one, not only from its own intrinsic importance, but also from the valuable remarks elicited in the discussion.

He moved a vote of thanks to Mr. Collins for his paper and for the interesting collection of mineralogical specimens exhibited, which was passed.

The following paper was then read:—

ON THE MECHANICAL APPLIANCES USED FOR DRESSING TIN AND COPPER ORES IN CORNWALL.

By Mr. HENRY T. FERGUSON, of Truro.

The processes of Dressing Tin and Copper Ores have continued almost stationary for a long period, and the mechanical appliances employed have been of a very simple and crude character; but steps have recently been taken, with a fair amount of success, to extend the application of machinery for the purpose, and to introduce machines of improved construction. In many Cornish mines the lodes contain both tin and copper ores; and it has frequently been found that, when a mine has ceased to make a profit on working copper, owing to the lode becoming poor or exhausted, tin has been met with in the same lode below the copper, and the mine has continued to pay its way and earn good dividends from the tin; in fact most of the best tin mines have been rich copper mines originally.

The material is raised from the mine in skips or kibbles containing from 10 to 20 cwts. each. On reaching the surface it is tipped into a tram wagon, and run out along a tramway raised about 10 feet from the ground. The floors under the tramway are divided into spaces called "slides," into which the stuff is tipped from the wagons; each slide contains the stuff sent to surface by one set of men called a "pare," usually consisting of four men and two boys. The situation of the slides near the winding shaft is shown in the diagram, Fig. 1, Plate 37, which is a plan of the Dressing Floors at a tin mine, as usually arranged. The larger stones are broken up with sledge hammers by hand, which is called "ragging;" and are then further reduced by hand hammers to a size sufficient to allow of being passed through a 4 inch ring; this is called "spalling." In some mines both these operations are now

superseded by the use of Blake's stone-breaking machine. The contents of each of the slides are kept separate, and after spalling are divided into heaps or doles, those containing tin being placed on one side, and copper on the other, wherever the two minerals are found in the same lode. The percentage of ore contained in these doles is then ascertained from samples by the assayer on the mine, and the miners are paid in proportion to the value found; in this arrangement the miners are said to be working on "tribute."

Tin Dressing.—In dressing the ores the object is to separate the ore itself from the large proportion of foreign matter with which it is associated in the lodes, the ore itself amounting to only from 1 to 2 per cent. of the whole stuff raised. The ore of tin is a peroxide, which when pure contains 78·6 per cent. of metallic tin and 21·4 per cent. of oxygen. The impurities with which it is associated are mostly quartz, iron pyrites (sulphide of iron) commonly called "mundic," yellow copper ore (sulphide of copper and iron) commonly called "copper pyrites," arsenic, sulphur, cobalt, and wolfram (tungstate of iron and manganese). The specific gravity of these minerals is shown in the following table, which is particularly interesting in consequence of the circumstance that the principle of dressing the ores consists mainly in separating the particles by taking advantage of their difference in specific gravity:—

	Specific Gravity.
Sulphur	2·03
Quartz	3·00
Copper pyrites	4·25
Iron pyrites, or Mundic	4·90
Arsenic	5·00
Cobalt	5·00
Peroxide of Tin	6·50 to 6·90
Wolfram	7·00 to 7·50

Stamping.—The stone that has been ragged and spalled is ready for the next process of stamping, in which it is crushed by stamps to a fine powder. The Ordinary Stamps, shown in Figs. 2 and 3, Plate 38, are arranged in sets of four heads each, contained within a coffer or wooden box; each stamp consists of a rectangular

cast-iron head A, having a wrought-iron bar or lifter B cast into it; the lifter works through vertical guides, and is raised by a set of cams on a revolving shaft C, usually five in number, which act upon an arm keyed upon the lifter. The height of lift is about 10 inches, and each stamp head makes from 50 to 70 blows per minute, and weighs with its lifter from 6 to 7 cwts.; the quantity of stuff stamped by each head is from 15 to 20 cwts. per 24 hours. The tinstuff, as the broken stone is called, is brought to the stamps in tram wagons, and tipped upon an inclined plane known as the pass D and half-pass E; the inclination of the pass D is about 1 in $1\frac{1}{2}$, and that of the half-pass E about 1 in $2\frac{1}{4}$. The half-pass E, leading down to the coffer in which the stamps work, regulates the speed at which they are fed; and a gentle stream of water is discharged continuously upon the stuff in its passage down this inclined plane. The water remains mixed with the tinstuff in the bottom of the coffer, and the action of the stamps is to reduce the stuff gradually to a fine powder, the finest portion of which is carried off with the overflowing water, the flashing up of the water at each blow of the stamps causing it to carry off the finest material in suspension. The overflow takes place through gratings G in the front and sides of the coffer, consisting of thin copper plates called grates, which are perforated with very small holes varying from the size of a pin's head to that of only a needle point. The size of the holes is of considerable importance, and is determined according to the quality and degree of fineness of the stuff that is being stamped, and the proportion of foreign matter that it contains; usually the grates contain about 144 holes per square inch. The stamps are arranged in long rows, each cam shaft lifting sixteen heads or four sets; the number of heads depends upon the extent of the mine, and in some there are as many as twenty-five sets or one hundred heads. The disadvantage in the action of these stamps is that they produce a large proportion of "slime," or material so very finely pulverised that much of it remains permanently mixed with the water throughout the subsequent processes of separation, and thereby gets carried away as waste though containing tin ore. The production of slime by the stamps is in consequence of their slow action allowing much

of the pulverised material to settle down in the coffer and become further crushed to an unnecessarily fine powder, instead of passing out at once through the grates; and a quicker speed than 50 to 70 blows per minute cannot be obtained with the height of fall of these stamps.

Figs. 4 and 5, Plates 39 and 40, show Husband's Pneumatic Stamps, in which this difficulty has been met by an ingenious arrangement for greatly increasing the rapidity of the blows by the use of an air spring. The stamp head is not lifted direct, but is attached to a piston H working in an air cylinder K; and this cylinder has a reciprocating motion given to it by a crank shaft, through a forked connecting-rod that is coupled to trunnions upon the cylinder. When the cylinder is raised by the crank, the air below the piston is compressed, and the stamp is thrown up; and on the crank turning the centre, the air above the piston is compressed, and the stamp is driven down with a velocity considerably greater than that due to gravity. The stamp head and piston rod, weighing together nearly 3 cwts., are by this means made to have a fall of about 16 inches, with a stroke of only 10 inches in the crank, and a speed of 150 blows per minute: in comparison with a fall of only 10 inches in the ordinary stamps, and a maximum speed of only 70 blows per minute. A ring of small holes is made all round the cylinder immediately above and below the centre position of the piston, as shown in Fig. 6, Plate 40, so as to ensure both ends of the cylinder being filled at each stroke with air at atmospheric pressure. A continuous stream of water is made to flow through the hollow piston rod, for the purpose of preventing risk of heating by the compression of the air in the cylinder; this water is discharged through small holes at the bottom of the piston rod, just above the stamp head, and serves as part of the supply of water for the stamping operation. The main portion of the water supply to the stamp head is delivered in a circular jet, under a pressure of several feet head, upon the outside of the piston rod, where it passes through the cover of the coffer, as shown in Fig. 8. In order to prevent the unequal wear of the stamp head that would arise from the supply of fresh

uncrushed stone being on one side only, an arrangement is made for turning the head round into different positions at regular intervals. This is done by a horn L fixed on the piston rod by a set-screw and working between two vertical guide bars, as shown in Fig. 7; and about once per day the position of this horn is shifted so as to turn the piston rod partly round, and cause the stamp head to wear in a fresh place. These pneumatic stamps are erected in pairs, and stamp from 8 to 10 tons per head per day, in comparison with only $\frac{3}{4}$ to 1 ton per head per day, the work of the ordinary stamps; the comparative consumption of coal per ton of ore stamped is also in favour of the pneumatic stamps. They have an important advantage in portability; and in the case of starting new mines they can be readily transported from one point to another if found desirable, requiring but little foundation.

The pulverised stuff comes away from the stamps in a state of sand and slime, containing the tin ore mixed with a very large proportion of foreign matter, the ore not amounting to more than $1\frac{1}{2}$ to 2 per cent. of the whole; and the object of all the subsequent processes is to separate the ore from the rest of the maferial. This is effected by taking advantage of the greater specific gravity of the tin ore than of the other materials with which it is mixed: excepting as regards the wolfram, which is dealt with by chemical means. The stream of sand and slime flows away from the stamps over a floor F, Fig. 3, Plate 38, placed at an inclination of about 1 in 12, and passes into the "strips," which are wooden troughs from 20 to 30 feet long, 18 inches wide, and 12 inches deep, placed at right angles to the line of the row of stamps. The pulverised stuff is here deposited according to its specific gravity; the first portion or "head," at the upper ends of the strips, is the best, the middle the second best, and the lower end or "tail" contains the lighter particles, while the slime passes off into pits, where it is collected for further treatment. There is a great difference of opinion as to the utility of depositing the stuff in the strips; and at some mines the next process, which is that of "buddling," is commenced directly the stuff is stamped.

Buddling.—The form of buddle generally used in the first stage of the buddling process is shown in Figs. 10 and 11, Plate 41, and is known as the Convex or Centre-head Buddle. It consists of a circular pit, about 22 feet diameter and from 1 to $1\frac{1}{2}$ foot deep at the circumference, with a raised centre 10 feet diameter, and a floor falling towards the outer circle at a slope of about 1 in 30 for a length of 6 feet. The stuff is brought to the centre of the buddle in launders A, into which a constant stream of water flows; and it is distributed upon the raised centre from a revolving pan B carrying a number of spouts, so as to spread the liquid stream very uniformly in a thin film, which flows gradually outwards over the whole of the sloping floor to the circumference. In its passage down the slope the material held in suspension by the water is gradually deposited according to its specific gravity, and the tin ore being the heaviest is the first thrown down, and is consequently in greatest proportion towards the centre of the buddle. The outflow C for the waste and slime from the circumference of the buddle is regulated by a wood partition perforated with horizontal rows of holes, which are successively plugged up from the bottom as the height of the deposit in the buddle rises. To facilitate the uniform spreading of the stuff over the floor of the buddle and prevent the formation of gutters or channels in the deposit, a set of revolving arms D are employed, from each of which is suspended a sweep carrying a number of brushes or small pieces of cloth, and these being drawn round on the surface of the deposit keep it to an even surface throughout; the distributing spouts and sweeps are driven at about five or six revolutions per minute. In Figs. 12 and 13, Plate 42, is shown Martin's buddle, in which the stream of stuff supplied to the buddle is itself made to drive the revolving centre pan and sweeps, the supply launder A delivering the stream upon a small water-wheel E geared to the pan B.

As the deposit accumulates in the buddle, the sweeps are successively raised to a corresponding extent; and the process is thus continued until the whole buddle is filled up to the top of the centre cone, which usually takes about ten hours. The contents are then divided into three concentric portions, each about

a third of the whole breadth, which are called the head, middle, and tail; the head, or portion nearest the centre, contains about 70 per cent. of all the tin in the stuff supplied to the buddle, the middle nearly 20 per cent., and the tail, or portion next the circumference, contains only a trace; the remaining particles of tin are carried off by the water in the state of slime.

The heads from several buddles are then shovelled out, and thrown into a trough or launder, into which a stream of clear water flows, of sufficient quantity to convey the stuff to another buddle of a different construction, the Concave Buddle, shown in Figs. 14 and 15, Plate 43. The stuff is supplied at the centre of the buddle as before, but is conveyed from thence direct to the circumference, by revolving spouts that deliver it in a continuous stream upon a circular ledge, from which it flows uniformly over the conical floor falling at a slope of about 1 in 12 towards the centre; it is kept uniformly distributed by means of revolving sweeps, as in the previous buddle. The greatest portion of the tin is in this case deposited round the circumference of the floor, and the slime and waste flow away through rows of holes in the sides of a centre well; as the depth of deposit increases, the level of the overflow is gradually raised by plugging up these holes in succession.

In Figs. 16 and 17, Plate 44, is shown an improved construction of Concave Buddle by Mr. Edward Borlase, now in extensive use at several mines, which has a mechanical arrangement for adjusting the level of the central outflow, by raising a ring R that slides upon the centre vertical shaft, as shown in the detail view to a larger scale. By this means the height of the outflow is adjusted more gradually and uniformly than by the plugged holes in the ordinary buddles, and there is less liability to waste by guttering. The sliding ring R is raised by hand by the rod I and lever L provided with the double adjusting nuts N; and the arms of the sweeps D being supported upon the rising ring are kept constantly at the proper height by the same adjustment. A mechanical agitator M at the head of the feeding launder stirs up the stuff before entering the buddle.

Another form of buddle has been recently introduced, called the Propeller Knife Buddle, which is shown in Figs. 18 to 20, Plate 45. It consists of a cylindrical frame, $9\frac{1}{2}$ feet long and 6 feet diameter over all, rotating on a horizontal axis, and carrying a series of scrapers or knife blades arranged in spiral lines round its circumference, which revolve close to a cylindrical casing lined with sheet iron, but without touching it; the casing forms the bottom of the buddle, and extends rather less than one quarter round the circumference of the revolving frame, as shown in Fig. 20. The tinstuff is supplied at one end of the buddle from the hopper A, and is made to traverse gradually along the whole length to the other end by the propelling action of the revolving knives, which are fixed obliquely and follow one another in spiral lines round the cylindrical frame. A gentle stream of clear water flows down over the whole curved surface of the bottom of the buddle from a trough B along its upper edge, and washes away continuously into the two side hutches C and D the lighter materials that are mixed with the tin ore, whilst the particles of tin ore remain behind on the bottom of the buddle, and are gradually propelled to the further end, where they drop over the edge into the receptacle E. The machine is driven at about 20 revolutions per minute, giving the knife blades a speed of about 370 feet per minute. The action of this machine is found to be very perfect, the whole of the stuff being continually turned over by the knife blades and pushed upwards against the descending stream of water, which washes out the lighter particles; the result is an unusually complete separation of the tin ore, in a single operation, with only a small proportion of loss in the waste. The contents of the second waste hutch D are so poor as not to pay for any further dressing; and the waste in the first hutch C containing a small proportion of slime tin is passed through the buddle a second time.

Tossing and Packing.—The process of buddling is repeated three or four times in successive buddles, for further separating the foreign matter from the tinstuff; and the latter is then subjected to the process called "tossing." It is put into a tub or "kieve," about $3\frac{1}{2}$ feet diameter and $2\frac{1}{2}$ feet deep, and having been mixed with an

equal bulk of water is then stirred up with a shovel continuously in one direction until the whole of the stuff is in a state of motion; the object is in this way to get rid of the finer particles of foreign matter, the buddling having separated all the heavy matrix. The stuff then undergoes the process called "packing," which consists in tapping the side of the kieve with a heavy iron bar continuously for a period varying from a quarter of an hour to an hour; the bar is held vertically with one end resting on the ground, and with the upper end repeated blows of about 100 per minute are struck by hand against the edge of the kieve. This keeps up a constant gentle vibration in the contents, and facilitates the separation of the tin ore, which gradually settles down to the bottom of the kieve. Instead of a bar worked by hand labour, a hammer worked by mechanical means is employed at some mines for performing the packing, with the advantage of maintaining complete regularity in striking the blows for any length of time required. When the packing is finished, the upper portion of the stuff in the kieve is skimmed off and buddled over again; and the remainder, now called "whits," is taken to the burning house to be calcined. The kieve is completely cleared out, before being refilled with a fresh charge.

The Ore Dressing Machine of Mr. Thomas Borlase, shown in Figs. 21 and 22, Plate 46, consists of a slowly revolving annular table, 24 feet diameter and 6 feet wide, placed at an inclination of 1 in 12 to the horizontal. The stuff to be dressed is supplied on the upper side of the table by a fluted spreader A, and the heavier or richer portion is deposited at once close to the circumference, while the poorer stuff is carried to the inner part of the annular table, and the waste runs off over the inner edge into the circular trough B underneath. A gentle stream of clean water supplied at C, immediately adjoining the spreader A, cleans the rich ore deposited near the circumference of the table, washing off into the centre space any of the waste that may have adhered to the table. At the lower side of the table jets of pure water wash off first into a receptacle D the outer ring of rich stuff, which extends about 2 feet in from the outside edge; and afterwards the inner and

poorer portion, called "craze," into a second receptacle E. The table makes one revolution in about three minutes; and in the half revolution from the upper to the lower side of the table, it is found that stuff containing originally only about $1\frac{1}{8}$ per cent. of tin ore is brought up to as much as 15 per cent. The richest stuff or "whits," lying at the head of the first "strip" or tye D, is fit to be taken direct to the calciner, without requiring further dressing previously.

Calcining.—The next process is roasting or calcining the partially dressed tinstuff or "whits," for the purpose of getting rid of the arsenic, sulphur, and other volatile impurities, and also to facilitate the subsequent removal of other foreign materials. Two kinds of Calciners are now in use. The older one, known as Brunton's Calciner, consists of a horizontal revolving table, about 12 feet diameter, enclosed in a shallow reverberatory furnace; the table is slightly conical in shape, its surface sloping downwards from the centre to the circumference. The tinstuff delivered on the centre of the table through a hopper in the roof of the furnace is exposed to the flame passing through the furnace, and is continuously stirred by a set of scrapers fixed in the roof whilst the table rotates very slowly below them, making only about six revolutions per hour. The scrapers being set obliquely shift the stuff gradually from the centre to the circumference of the table, where it falls off, and is collected in a chamber beneath.

In Figs. 23 to 25, Plate 47, is shown Oxland and Hocking's Calciner, which is now adopted at several mines. It consists of a long wrought-iron cylinder A, lined with firebrick, 3 feet inside diameter and 32 feet long, placed at an inclination of 1 in 16 to 1 in 24 according to the nature of the stuff to be treated, and supported upon rollers, upon which it is made to revolve at a very slow speed of six or eight revolutions per hour. The tinstuff or "whits" is supplied into the higher end of the cylinder through a hopper fitted with a feeding screw B, and gradually traverses the length of the cylinder to the lower end, where it falls into a chamber C, from which it is removed for further treatment. The

heating furnace D opens into the lower end of the cylinder, and the volatilised arsenic and sulphur &c. are carried off by a flue E from the upper end; this flue is extended to a considerable distance and divided by baffle walls into a succession of chambers, in which the arsenic is deposited and periodically collected. The time taken for the stuff to pass through the calciner is from three to six hours. The firebrick lining of the calciner is constructed with four longitudinal ribs projecting internally, as shown in the transverse section, Fig. 24, and extending two thirds of the length from the lower end, as shown in Fig. 23; in the revolution of the calciner these have the effect of continuously stirring the stuff and exposing the whole of it to the heat. In this calciner the stuff being supplied at the upper end, furthest from the heating furnace, is exposed first to the lowest heat; and afterwards to a gradually increasing heat, as it works its way along to the hotter end of the calciner; by this means the most advantageous effect is obtained from the fuel consumed in the furnace. The stuff comes from the calciner in the state of a fine dry powder, which is cooled with water and taken again to the buddle; and the whole of the previous processes of buddling, tossing, and packing are again gone through, and repeated a number of times, according to the quality of the ore, until this is finally in the condition ready for smelting; and it is then sold as "black tin."

Results of Dressing.—The whole process of dressing the tin ore for smelting occupies usually from eight to ten days, including the stamping; and the result obtained is an increase in the proportion of pure oxide or black tin from $1\frac{1}{2}$ or 2 per cent. in the tinstone raised from the mine, up to 95 per cent. in the finally prepared ore that is sold for smelting. As tin dressing is only a process of separating by mechanical precipitation a very small proportion of saleable produce from the large mass of mineral through which it is disseminated in minute crystals, it is essential that the greatest precautions should be taken to prevent any waste of the valuable product. For instance, in buddling, the occurrence of any gutters or channels down the sloping surface of the stuff in the buddles would immediately cause the larger and more valuable grains of tin

ore that are first deposited at the top of the slope to be carried away with the water and slime. The grains of tin which do pass off with the slime even from the best buddles are very fine and light; and notwithstanding all the care that is taken in dressing the slimes, large quantities of tin ore are washed away from the dressing floors of the mines into the numerous streams and rivers of the district. The slimes are consequently intercepted at successive works on a stream or river coming from a series of mines, and large quantities of tin are collected by treating them in hand frames and concave buddles at a very small expense, the stream itself working a small waterwheel which drives the buddles, while the frames are attended only by a few children.

Treatment of Slimes.—A very simple and clever form of Self-acting Slime Frame or "Rack" is shown in Figs. 26 to 28, Plates 48 and 49, by means of which the attendance requisite is so far reduced that one boy is able to attend to twenty frames. The launder A bringing the slimes from the buddles passes between two rows of the slime frames, set back to back, and the delivery to each frame is distributed by a fluted spreader B, as shown in the plan, Fig. 28, and then flows uniformly in a gentle stream over the surface of the frame, which is at a slope of 1 in 7, and is divided at the middle into two halves by a 5 inch step; the waste flows off at the bottom of the frame into the launder C. The stuff deposited on the frame is then flushed off at successive intervals of a few minutes each, by a self-acting contrivance consisting of two rocking troughs D D, which are gradually filled with clear water from a launder E; when full they overbalance, and discharge their whole contents suddenly upon the top of each half of the frame. The tipping movement of the troughs opens at the same time the covers of two launders F F, one at the foot of each half of the frame, into which the stuff deposited on the frame is washed by the discharge of water, the two halves being kept separate because the greater portion of the tin ore is retained on the upper half of the frame. The re-adjustment of the whole into the original position is effected by a cataract G of simple construction.

Pulverising.—The difficulty in dealing with the slimes arises from the circumstance of the grains of tin ore being so minute, compared with the particles of foreign matter with which they are mixed, that they are carried away in suspension by the water, in consequence of their extreme absolute lightness, although their specific gravity is greater than that of the larger particles of foreign matter they are mixed with. For the purpose of reducing these larger particles of foreign matter to the same size as the tin grains, and thereby enabling the latter to be separated by the ordinary dressing processes with water, several different machines called "pulverisers" have been introduced, having either a reciprocating or a rotary action; these have been found very successful in reducing the particles to a uniform size, and thus affording the means of utilising the waste, or "roughs" as it is called, which was previously thrown away because the cost of reducing it by re-stamping was greater than the value of the tin ore obtained by such a process.

In Figs. 29 to 32, Plates 50 and 51, is shown Dingey's Pulveriser, which is in successful operation at several mines in this country and abroad. It consists of a shallow pan A of 6 feet internal diameter, having vertical sides fitted with a series of grates, through which the pulverised material is delivered. Four annular grinding discs or runners B B, $2\frac{1}{2}$ feet diameter and geared together, revolve upon the bottom of the pan at a high speed of 200 revolutions per minute; and the pan itself is made to revolve slowly, at about 4 or 5 revolutions per minute, so as to avoid any tendency to wearing in grooves. The wearing surface of the bottom of the pan is a separate cast-iron plate, with a number of holes in it, Figs. 31 and 32, forming shallow recesses in which the stuff to be pulverised is retained whilst the grinding runners act upon it. The stuff mixed with a stream of water is supplied by a launder C into a central annular trough D, Fig. 31, from which it is delivered by spouts into the centre of each of the grinding runners; and having been ground by passing under the runners, it escapes with the water through the grates in the sides of the pan into the external trough E, whence it is conveyed direct to the buddles.

The shoes of the grinding runners as well as the bottom of the pan are made separate castings, $1\frac{1}{2}$ inch thick, so as to be readily replaced when required; at F, Fig. 32, is shown a plan of one of the runner shoes. The space between the grinding faces of the shoes and the bottom of the pan is adjusted by the hand regulating screws and levers G G supporting the runner spindles. The weight of the whole machine is about 4 tons, and it will grind from 15 to 20 tons per day of 24 hours, according to the class of stuff.

The importance of reducing the waste in the dressing processes is shown by the fact that more than £30,000 per year is realised in one stream alone, called the Red River, from stream works supplied entirely by the stuff that leaves the mines as waste, this being wholly lost to the adventurers of the mines from which it was raised. The total quantity of tin ore raised in Cornwall and Devon in the year 1871 was 16,800 tons, value £1,068,000, showing an increase of nearly one half over the annual quantity raised ten years previously.

Copper Ore Dressing.—Copper Ore is raised in the same manner as previously described with regard to tin ore, but it presents a marked contrast to tin ore in being very much less finely disseminated throughout the lodestuff with which it is associated; the coarser spots or patches in which it is met with necessitate consequently a very different treatment from that adopted in dressing tin ore. The most abundant ore of copper is yellow copper ore, also called "copper pyrites," which has a bright yellow colour, much like good brass; it is a sulphide of copper and iron, containing when pure only 34·6 per cent. of copper, with 30·5 per cent. of iron, and 34·9 per cent. of sulphur. The other principal ores of copper are the red, black, grey, purple, and green ores. The red and black ores are oxides, containing when pure 89 and 80 per cent. of copper respectively; the red, which is the more common of the two, is quite brittle, and is easily broken up into a red powder. Grey copper ore is a sulphide, containing when pure 80 per cent. of copper; it has much the appearance of metallic lead, but may be

broken up by a hammer. Purple copper ore, also called "horseflesh ore," is a sulphide, but not so rich as the grey, part of the copper being replaced by iron; when pure it contains nearly 70 per cent. of copper. Green copper ore, or "malachite," is a carbonate, and is much less common than any of the others; it contains when pure 57 per cent. of copper. None of these ores of copper are very hard, all being readily scratched with a knife.

The ore as raised from the mine is tipped into spaces called "slides," in quantities averaging from 5 to 20 tons in each slide. The larger stones having been separated, and "ragged" or broken up into smaller pieces by hand hammers, the whole is passed through two revolving riddles of different mesh, and then hand-picked by children and sorted into three qualities. These are called "prills" or best, consisting of pieces of very nearly pure ore; "dradge" or second quality, in which the ore is more or less interspersed with matrix; and "halvans" or leavings. As much of the best as will pass through a riddle of $\frac{3}{4}$ inch mesh is taken at once to the pile ready for market, and the rest goes to the crushing rolls to be crushed down smaller. The second quality has to undergo both crushing and jigging.

Crushing.—The Crushing Rolls, shown in Figs. 33 to 36, Plates 52 to 54, are a pair of chilled cast-iron rolls A and B, 24 inches diameter and 16 or 18 inches long, fixed horizontally side by side and driven at about eight revolutions per minute. One of the rolls A is coupled to the main driving shaft, and the other B which is driven from it by gearing is mounted upon sliding bearings, and pressed up against the fixed roll A either by two weighted levers C C or in some cases by springs, the object being to allow any extra large stones or foreign substances to pass through without injuring the rolls. Each roll consists of a cylindrical hoop, cast with the centre hole octagonal, as shown in Fig. 36, and secured upon the spindle by wedging and cottering, so as to admit of being readily renewed when worn out. The ore is tipped from a tram wagon into a hopper above the rolls, and after passing through them it falls into a shoot below, by which it is conveyed to an inclined revolving screen or riddle D,

having holes $\frac{5}{8}$ inch square and making 32 revolutions per minute. The pieces that are too large to pass through the screen are delivered from its lower end into the rim of the revolving raff wheel E, the cups of which raise the stuff to the upper floor, where it falls over an inclined plane F into the hopper, and is again crushed by the rolls until all reduced to a size small enough to pass through the screen D. The best and second quality ores are crushed separately; the former does not require any further treatment, and is ready for the market. The second quality is taken to the jigging machines for further separation.

Jigging.—The Hand Jigging Machine, shown in Figs. 40 and 41, Plate 57, consists of a large trough or "hutch," through which a constant stream of water flows; and over the centre of the hutch is suspended an oblong sieve A, having about 25 holes per square inch, upon which is spread a filter bedding of coarse ore in a layer about $\frac{3}{4}$ inch thick. The stuff to be jigged is then placed in the sieve, which is lowered into the water by the hand lever B, and a vertical jerking motion is given to it continuously by hand for about five minutes; the connecting-rod C at the back end of the hand lever B passes through an eye in the end of the upper lever D carrying the sieve, and has a stop fixed upon it above and below the end of the lever D, leaving a certain amount of play between, whereby the jerking action is produced on working the hand lever B up and down, which causes the heaviest pieces of ore to settle down to the bottom of the sieve. When the stuff has been jigged long enough, the sieve is raised out of the water, and the light particles on the surface, which contain only a very small quantity of ore, are skimmed off, and thrown away as waste, or to be worked over again if considered of sufficient value; the middle part is laid aside to be crushed again; the bottom contains the best ore, being the heaviest, and is fit for sale, together with all the smaller particles that have fallen through the sieve into the bottom of the hutch. In the self-acting jigging machine, which is similar to the hand jigger, the jigging motion is produced by a cam on a revolving shaft driven by steam or water power.

An improved form of jigging machine, Collom's Jigger, is in use at Restronguet Tin Stream Works for washing stream tin, and appears to be equally applicable to copper dressing; it is in extensive use for dressing lead and other minerals in Wales and in some foreign countries, but has only very recently been introduced in Cornwall for tin dressing; like all other jigging machines it is only applicable for dressing stuff from which the slimes have been previously extracted by a proper separator. This jigger is shown in Figs. 37 to 39, Plates 55 to 57. The jigging action is produced by two pistons G G, fitting loosely in square trunks, and having a very short vertical stroke of from $\frac{1}{2}$ inch to 1 inch; coarse ore requires the longest stroke. Each piston is struck down alternately by the blows of a rocker H, and raised again by a spiral spring upon the piston rod, which brings it up against an adjustable stop J; the rocker H is actuated by a crank making about 120 revolutions per minute. The space under each piston is in communication with one of a pair of hutches K K, as shown in the transverse section, Fig. 39; and on the top of each hutch is fixed a fine sieve of brass wire, upon which is spread a bedding of coarse ore in a layer about $\frac{3}{4}$ inch thick. The stuff to be jigged is supplied through a launder L with a continuous gentle current of water, and is delivered upon one end of the sieve through a distributing grate M; the sieve is set with a slight fall of about 1 in 140 towards the opposite end. The hutches are kept constantly filled with a supply of clear water under a pressure of 2 feet head or upwards by the pipe P, and there is a constant overflow of water from the lower end of the sieves, carrying away the lighter stuff that is separated by the jigging process. The pulsating action of the pistons gives a jerking motion to the water under the sieves, driving it up through them, and producing the same effect in separating the stuff upon the sieve as in the ordinary jigging machines where the sieve itself is jerked up and down in the water. The lighter particles are thus lifted and gradually carried off in the stream of water flowing over the sieve, leaving the heavier rich stuff to settle down gradually through the sieve into the hutch below, from which it either passes off continuously through a regulating hole at bottom, or is discharged

at intervals if the supply of water is scarce. In order to prevent accumulation upon the sieves of any stuff which may be too light to pass through the bedding on the sieves, yet too heavy to be carried over the lips of the hutches by the overflowing stream of water, "ragging gear" R is in some cases provided, consisting of a row of holes closed by taper plugs fitting into conical seatings; the height of the plugs is adjusted by thumb-screws so as to regulate the area of the openings according to the quantity of stuff to be got rid of, which never amounts to much; this falls through into a separate compartment S of the hutches, and passes out through a hole at bottom. A second complete jigging machine is fixed immediately in front of the first and at a few inches lower level, by which the overflow from the first is received and worked over a second time in a similar manner.

In this jigger a very complete separation of the different qualities of ore is effected by an entirely self-acting process, and with a very small proportion of loss in the waste. In the use of the jigger at the Restronguet Tin Stream Works, for separating the tin from the gravel and sand in which it is found, almost the whole of the tin ore contained in the sand becomes deposited in the upper pair of hutches, the contents of which are then worked over in the propeller knife buddle; from the sand deposited in the lower pair of hutches some inferior ore which requires stamping is extracted in an ordinary "strip." There is a large amount of slime with the tin sand raised at these works, but it is separated from the sand before the stuff passes on to the jiggers, by a slime separator attached to each jigger. The sand that passes off through the "ragging gear" requires to be stamped to a finer size, and is then washed over again.

Sampling.—The piles of dressed copper ore from the several processes previously described are mixed together, weighed, and a sample taken of the average quality, the value of which is ascertained by an assayer; and the whole is sold at the public sale of copper ores, which now takes place about once a quarter, instead of every month as formerly when copper mining was in a flourishing

state in the district. There has been a gradual falling off in the quantity of copper ore raised in Cornwall, owing to the lodes becoming exhausted and other causes; the total quantity raised in Cornwall and Devon in 1871 was only 67,000 tons, value £316,000, while the annual quantity raised ten years previously was two and a half times as great.

In conclusion the writer has the pleasure of acknowledging the valuable assistance rendered in the preparation of this paper and the accompanying diagrams, by Capt. Teague, Mr. John Hocking, Jun., Capt. Maynard, Capt. James, and other mine captains or agents, who have kindly supplied practical information and working drawings for the purpose.

Mr. Ferguson exhibited a series of specimens of tinstuff in the various stages of manufacture,—as it passed from the stamps, and after buddling, calcining, and "packing," and finally as it was sold to the smelter. He remarked that the increased weight of equal bulks of the successive specimens was a very good criterion of the increased value of the ore as it approached the final state of black tin. Some of the samples exhibited of copper ore were seen to be rich enough to be sold at once as they came from the lode, without any dressing; others had to be dressed, as described in the paper, and sometimes copper ore of inferior quality was stamped, instead of being crushed by rolls, after which it passed through the various other operations, whereby it was finally brought into a state fit for sale. A working model was also exhibited of Borlase's revolving ore dressing machine, in use for dressing tin ore, as described in the paper.

Mr. Richard Taylor said all Cornishmen would confess that until recently the dressing of ores in Cornwall had been as rude as possible; and he himself recollected the time when none of

the modern processes described in the paper as now in use were known. The buddling process, for instance, performed now by means of mechanical buddles, had in former times been called "trunking," because then carried on in common rectangular troughs sunk in the ground, each of which required considerable hand labour to work it. Jigging also, which was now rightly regarded as so very important an operation, was then done with a little common round sieve by boys, who had to work stooping, so that their heads were down near the surface of the water tanks in which the sieves were used, these tanks too being sunk in the ground. That state of things was universal when he first came into the county. The first jigging machines ever erected in Cornwall had been introduced by himself at the Consolidated Mines in Gwennap about forty-two years ago. The first machines of the kind had been constructed by a Cornishman at a lead mine at Grassington in Yorkshire, belonging to the Duke of Devonshire; and when they were introduced by himself into Cornwall, his neighbours in Gwennap anticipated that all the persons then engaged in jigging the ores would be thrown out of employment and starved, and it had been a matter of some difficulty to convince them of the inefficiency of the old method and that there was a great deal of valuable stuff thrown away by it.

At the same time the first crushing machine used in the west of the county was erected at the same mines. There had previously been one in use in the eastern part of the county near St. Austell, and also in Devonshire. The crushing machine he believed had been invented by his father, and had been first used at Crowndale copper mine near Tavistock. In the year 1806, the price of copper being then very high, that mine had produced a large quantity of ore, which occurred much disseminated through the waste matter. There was not sufficient labour on the mine to deal with this quantity of material, although more maidens had been imported from Cornwall for the purpose; and one day his father remarked, in answer to the apprehensions of the agent, "I will make a cast-iron maiden for you." The first crushing machine was accordingly made by him by taking two lengths of a cast-iron pump,

of 16 or 18 inches diameter, to serve as the cylinders or rolls, and stopping up the ends and fixing driving axles in them. This was found to give a satisfactory effect, and properly constructed crushing machines were afterwards made. Crushing machines had been of very great service in English mining, and at the present time very good machines were in use, but the construction had not been much improved within his own recollection. To these had now been added Blake's stone-breaker, of American invention, which had hitherto been used chiefly for breaking large stones of ore down to the size of road metal; but latterly the maker, Mr. Marsden, had introduced what were called pulverisers, much of the same construction as the stone-breakers, but differently proportioned, which were intended to reduce the stuff as fine as the ordinary crushers and at a much less cost. In his own opinion, as a manufacturer of cylinder crushers, of which a great number were made at the works near Chester with which he was connected, for export as well as for use in this country, these pulverisers were likely to crush much more cheaply than could be done by an ordinary cylinder machine, and he believed therefore they might in some cases supersede the cylinder machines.

Next in importance to the crushing rolls, even in copper dressing, used to be the stamps, which were formerly employed much more extensively for copper dressing than they were at the present time; in fact for that purpose he believed they had now almost gone out of use. For tin dressing however stamping machines were of very great importance, because of the necessity for pulverising the tinstone so fine in preparation for the subsequent dressing operations. The ordinary Cornish stamps, though originally very rude, might be said to be now almost as good as they were likely to be in the usual form; many improvements had been made in stamping machinery, and particularly in the gold countries, Australia and California, much had been done in improving the ordinary stamps; but the admirable invention of the pneumatic stamps by Mr. Husband was one which he hoped was destined to render more perfect the pulverising of tinstuff, and to reduce greatly the cost of dressing the tin ore. The

importance of such a result was seen to be very great, when it was considered that in a great deal of the tinstuff raised from the mines the tin ore was so small in quantity and so finely disseminated as not to be visible at all to the naked eye; at the Charlestown tin mines, for instance, near St. Austell, it was very rare indeed for any tin ore to be visible in the stone; and hence indeed it was a common phrase in Cornwall to say of a clever fellow that he "knows tin." It had already been stated that much of the tinstuff raised in Cornwall yielded only about 1 per cent. of tin ore, and that it was quite common for 50 or 60 tons of stuff to be dealt with in order to produce one ton of black tin. This rendered it necessary to pulverise the ore in such cases to a great degree of fineness; but at the same time it was highly important that the tin should not be brought down finer than was absolutely necessary. The treatment of tin ores was very different in different mines according to the differing quality of the tinstuff. In a good many mines the grains of tin were very clearly to be seen in the stone in the form of well defined crystals; it was most undesirable to reduce these grains of tin further, or indeed at any stage to carry the reduction of the tinstuff further than was required for disengaging the particles of tin from the matrix; if the reducing process were carried any further it had the objectionable result of increasing the quantity of slimes and thereby conducing to waste of tin. Those who visited the Restronguet tin stream works would see a remarkable instance there of the grosser form of tin ore, which was there found in the form of sand and gravel and pebbles of considerable size, but by far the larger proportion of the tin was found in the sand, which was fine. The mode of dressing at those works, which were hardly to be called a mine, consisted in washing the sand, mixed with the gravel. It would be necessary to stamp the pebbles, and preparations were being made for that purpose. The sand was nearly all pure tin ore, that is, the individual grains consisted of pure black tin, but these were more or less interspersed with grains, not indeed of wolfram in this instance, but of "mundic," that is iron pyrites or arsenical pyrites, which was not quite so troublesome to deal with as wolfram.

The specific gravity of pyrites was so near that of tin ore, that they could not be separated by the mechanical process of washing; and it became necessary therefore to employ chemical agency, calcining the stuff so as to drive off the sulphur or arsenic from the pyrites and leave only oxide of iron, the specific gravity of which was sufficiently below that of the tin ore to allow of then completing the concentration of the latter by the same washing processes that were employed in the earlier stages of the dressing, the iron being thereby washed out and the tin ore left very pure. The process of calcining, for which Oxland and Hocking's calciner described in the paper was now coming into use, was not indeed universally necessary in tin dressing, because it was not always that the tinstuff contained mundic. The black tin as delivered to the smelting works was generally in as pure a state as had been mentioned, containing as much as 95 per cent. of pure tin ore.

Collom's jigging machine, which was an American invention, had been taken up in this country by his brother, Mr. John Taylor, and tried for a few years past, and a great number had now been made at their works. For lead dressing these machines were excellent, and judging from the experience of their operation with lead ore he looked to them as likely to be extremely useful also for copper ore and for the coarser-grained tinstuff. Great advances had been made in Germany in respect to self-acting jigging machines, and he had lately seen several other new jiggers at work there, as well as many other machines which would be found very useful in this country; Collom's jigger however was the best that he had seen, and the most completely self-acting. One of these jiggers would be seen in operation in the visit to the Restronguet works.

Another machine which would be seen at work at Restronguet was the propeller knife buddle. This also was a new implement in Cornwall, having never before been introduced into the county; it was the invention of a Cornishman, named Vigurs, a captain dresser at the lead mines under Mr. John Taylor's management in Cardiganshire, and it had been extensively used there for many years. Since then it had also been used at lead mines in Spain,

where it had been found most efficient; at Linares the ores were stated by Capt. Tonkin to be so perfectly dressed by it that no further process was wanted for them. At Restronguet its use had proved very successful indeed for tin dressing; the sandy part of the tinstuff, which had been separated from the gravel by the washing in Collom's jigger, was taken thence to the knife buddle, and by being passed once or twice through was rendered perfectly clean and ready for smelting. No attendance or labour whatever was necessary, excepting only the labour of supplying the stuff to the buddle. This also was a machine which he saw no reason to doubt might be profitably applied to the dressing of copper ores just as well as lead ores.

The Chairman asked for some information as to how the wolfram was removed from the tin; this separation appeared to be the crowning difficulty in tin dressing, and it had been stated that chemical agency had to be resorted to for effecting it.

Capt. John Maynard, of East Pool mine, said they had had a good deal of experience at that mine in dealing with wolfram, as some of their tinstuff contained rather a large proportion of this substance. Their practice was to dress the stuff in the ordinary way as at other mines by the buddling and tossing processes, and then to calcine it to get rid of the arsenic and sulphur; the whole of these operations were then repeated, after which the stuff had to be buddled and tossed again several times. After this ordinary dressing, it was mixed with soda ash in the proportion of 50 per cent. of the quantity of wolfram which the stuff was found to contain. The whole was then subjected to a great heat in another furnace for about four hours, being occasionally stirred during the time, whereby the wolfram, or tungstate of iron and manganese, was decomposed, and tungstate of soda formed by the tungstic acid uniting with the soda. It was pretty well known by the appearance when the stuff had been sufficiently burned, and it was then drawn from the furnace and thrown into a tank for the purpose of lixiviation. It often occurred that the stuff got baked in such hard masses in the heating furnace as to

require to be broken up before it could be dressed; this was done by crushing it in a crushing machine or pulveriser, or occasionally by stamping it again with quartz; and the whole had afterwards to be dressed over again to prepare it for the market.

Mr. C. Cochrane enquired whether the tungstate of soda, which resulted from the decomposition of the wolfram or tungstate of iron in the heating furnace by the soda ash, was soluble, or whether it had to be removed by mechanical means.

Capt. Maynard replied that the tungstate of soda was soluble, and was washed out in solution by lixiviating the charge drawn from the furnace; then the oxides of iron and manganese which remained, though not soluble, were of so much lower specific gravity than the tin ore as to be readily separated from it by the subsequent ordinary dressing. The solution of tungstate of soda was drawn off from the lixiviating tanks into evaporating pans, where the water was evaporated over a slow fire until dry tungstate of soda remained, from which tungstic acid was obtained by treatment with hydrochloric acid.

The Chairman asked for some further information respecting the working of the pneumatic stamps.

Mr. W. Husband said he had been much gratified at hearing the pneumatic stamps spoken of so favourably by Mr. Taylor. The total weight of the head and lifter in these stamps was from 310 to 320 lbs., and it required about 12 indicated horse power to drive a pair of heads at 150 blows each per minute. From experiments upon different kinds of tinstuff it was found that from 8 to 10 or 11 tons per head could be stamped in 24 hours. The amount of fuel required to stamp the tinstuff at Carn Galver mine, about midway between St. Just and St. Ives, where two heads of the pneumatic stamps were driven by a combined engine with 9 and 17 inch cylinders, 15 inches stroke, and 70 lbs. steam, working by day alone, was about 5 cwts. of coal per day of 12 hours, with 1 cwt. of coal to bank up the fire at night, this result being equivalent to about $1\frac{1}{2}$ ton of tinstuff stamped per cwt. of coal. With the pneumatic stamps at New Rosewarne mine, Gwinear,

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196 tons of tinstuff had been stamped with a consumption of 156 cwts. of coal, or about $1\frac{1}{4}$ ton stamped per cwt. of coal; the average consumption of fuel for stamping purposes in the county he thought was not less than about 1 cwt. of coal per ton of stuff stamped. The quantity stamped with a given consumption of fuel varied of course very much with the fineness of the stamp grates, and also with the character of the stuff, the hardness of which was not of such consequence as its toughness, granite, quartz and elvan being easier to stamp than some kinds of clay slate. The advantage of the quicker blows given by each head of the pneumatic stamps was not merely that a larger quantity of stuff was stamped in the same time, but also that the quantity of slimes was diminished. The great object in stamping was to prevent the tinstuff being pounded down into the state of slime; and if the contents of the coffer were kept in a continual state of agitation, the stuff was driven against the grates continually, and when once it had come to the required size it could not remain in the coffer to be reduced into slime by further blows. Practically this had been found to be the result with the pneumatic stamps, the proportion of slime being considerably diminished by their use. It had also been found that the amount of iron worn away in the stamp heads was very much less than in the ordinary stamps, in which the average quantity of stuff that one ton of iron in the heads would stamp was from 300 to 400 tons in Cornwall. The pneumatic stamps he had found would stamp from 1000 to 1400 tons of stuff per ton of iron in the heads; at New Rosewarne between 6000 and 7000 tons had been stamped by the pneumatic stamps with the loss of 5 tons of iron in the stamp heads. This good result he attributed in great measure to the regular wearing of the heads. In order to ensure equal wear, the stamp head, as already stated, was periodically turned round; but if that were the only provision, the head would gradually wear into a point in the centre, and this was therefore provided against by casting the head with a hole up the centre, which was either filled with a core of soft iron or left empty (as shown in Fig. 9, Plate 40); with this construction the heads wore down evenly, retaining a tolerably flat face throughout.

To have a stamp that would stamp 1000 tons of stuff with only one ton of iron was a very important thing for machines that were sent out of this country; there were many places abroad to which stamping machinery was sent where the cost of carriage varied from £10 to £40 per ton, and in such cases therefore the difference between 500 tons and 1000 tons of stuff stamped per ton of iron was a saving of great importance.

With regard to the quantity of tin ore raised in Cornwall, which had been stated to have considerably increased during the last ten years, and to have amounted in 1871 to nearly 17,000 tons, he believed that by going back to an earlier date there would not be so large an increase to notice, as he remembered the quantity raised fifteen years ago had been about 15,000 tons in a year.

The Chairman enquired whether the pistons of the pneumatic stamps were packed, or whether they were merely made a fair fit in the cylinders. He asked also to what extent generation of heat would take place by the compression of the air in the cylinders, supposing the supply of cooling water were ever to be deficient or to be stopped altogether.

Mr. Husband replied that the pistons of the pneumatic stamps were fitted with light steel packing rings, which would last for three or four months' constant work before requiring renewal. The generation of heat would be very great, but for the circumstance that the alternate expansion of the air in the cylinders reabsorbed the heat generated by its compression; the stamps had been worked with only a very small quantity of water, not more than would pass through a quill with 3 or 4 feet head, and even with no water at all it had been found they could be run for about four hours without any injurious consequences. In addition to the stream of water through the hollow piston rod, there was also a little water kept constantly running over the cylinder; this ran down outside, and some of it got drawn in through the small holes in the sides of the cylinder, and thus served also to lubricate the piston.

Mr. H. Lawrence enquired what temperature was reached when no water was allowed to pass through the piston rod.

Mr. Husband said he had not had the means of trying the temperature by a thermometer, but that the heat was not anything considerable was shown by the circumstance that the cupped leather packings in the stuffing-boxes at top and bottom of the cylinder had not suffered any injury in running without water for three or four hours' constant working. But on one occasion, when it had happened that there had been an unobserved leakage of the compressed and consequently heated air past the cupped leather packings, these had been found to be destroyed by the heat. It was mainly to ensure the leathers not being damaged that the supply of water through the piston rod was required.

Mr. Richard Taylor said it would be very interesting if they could hear some remarks from Mr. Bolitho in reference to the quantity of tin produced in Cornwall.

Mr. T. S. Bolitho said, as regarded the production of tin in the year 1871, the quantity, as had been stated, was upwards of 16,000 tons of ore, containing about 66 per cent. of metal. There had been a considerable increase in the production for several years past; but now, in consequence of the increased price of labour and materials, and perhaps also the diminished price of tin, the quantity was steadily decreasing, to what extent remained to be seen. After a long experience however he had come to the conclusion that, unless there could be further improvements in the dressing of tin ore, the quantity raised in Cornwall would become considerably less than at present. In 1817, when Sir Stamford Raffles returned from the island of Banca, and saw the stamping mills and dressing processes then in vogue in Cornwall, he said to him, then a boy, "My little man, unless you can improve this, you will see the end of the mines of Cornwall." That the end had not yet been seen was due to the improvements in stamps and dressing which had since been made. Foremost among the improvers he wished to bear testimony to one whose name all Cornishmen should honour—William Brunton—who introduced the calciner. It could never be forgotten how much was owed to Watt and Trevithick, and perhaps also Woolf;

but next to them no man had done so much for Cornish mining as Brunton did by the introduction of the circular calciner. Although the advantages of the calciner were evident, very few mines used it until the patent had expired, and then it was found in operation throughout the length and breadth of the county.

Wolfram was a very great enemy to the tin smelters, but means had been found of dealing with it, for which they were greatly indebted to Dr. Oxland; and although still very far from perfect, the means suggested by him and adopted for the purpose had been productive of great good. Wolfram being tungstate of iron with a small percentage of manganese, and having very closely the same specific gravity as tin ore, when the tin ore contaminated with wolfram was heated with soda ash, as had been explained, the tungsten combined with the soda, forming tungstate of soda which was soluble in water, whilst the oxides of iron and manganese set free could be washed away, being of lower specific gravity than the tin ore. The process however was not yet so perfect as he hoped it might be made, and at present very great care indeed had to be exercised, for if too much soda ash was used, not only tungstate of soda but stannate of soda would be formed, and the tin would thereby be lost. This therefore was one point for further improvement.

There was one matter in which mechanical engineering might fairly be looked to for improvement, and that was the reduction of the tinstuff to a more uniform size of particles in the stamping process; a step in this direction had already been taken by the introduction of the pneumatic stamps, in connection with which reference had been made to the diminished quantity of slime produced by their action. Mention had been made of about £30,000 worth of tin going into the Red River annually, and being partly saved by dressing operations on the course of the river; and he happened to know that as much as £40,000 worth had been saved from that stream in one year. It might be said that this ore ought to have been saved at the mines; but there was one very great difficulty in accomplishing that, which was discovered originally at Great Wheal Vor near Helston. A quantity of sand from this

mine was washing down the Porthleven stream into the harbour of Porthleven, damaging the harbour by silting it up, and the old workers were compelled to erect a dam across the valley to stop it. This dam, called the "floe," led to the accumulation of an immense quantity of the sand; and some time afterwards, on its happening to be tested with a shovel, it was found that there was tin in it, and the result was that out of this pile of sand was recovered as much as £100,000 worth of tin, which would otherwise have gone to fill up Porthleven harbour. This and similar cases were not to be attributed to neglect at the mines, for the fact was that it was not possible to save this slime tin at the mines by any of the processes or appliances at present in use for tin dressing. Minute crystals of tin adhered to somewhat larger particles of matrix, probably quartz, and were floated away as sand to a considerable distance, so that they could not be collected except by being allowed to deposit in large ponds. In the course of three to five years this sand by the combined action of water and air became oxidised, and the minute particles of tin separated from the grains of quartz with which they had been associated; and the consequence was that tin could then be saved from a deposit of this kind, which a few years before, when the deposit was first formed, could not be extracted by any of the various dressing appliances in use. The difficulty was with regard to the stamped tinstuff, and if the pneumatic stamps would bring the tinstuff down to a more uniform size, they would be the means of a large quantity of tin being saved which was now washed away in what was known as slime. At present some portions of the tinstuff were not brought down small enough by the stamps, many of the grains retaining particles of matrix associated with the tin ore; while in other portions the crystals of tin ore themselves were crushed by stamping, and reduced so small as to be washed away in the slime. What was wanted was some process for ensuring if possible either a more uniform size of the pounded stuff as it came from the stamps, or a complete separation subsequently of the different sizes. This would do more good to tin mining in Cornwall than anything else; and he enquired how far such a result was obtained by the use of the pneumatic stamps.

Mr. Husband replied that the pneumatic stamps were partially successful in that respect, though not entirely so, the result of their use being that much less slime was made than by the ordinary stamps, but not absolutely none. At present, notwithstanding the careful and repeated dressing of the slimes by means of the dead frames, it was inevitable that much tin was still lost by being washed away with the waste; the endeavour to dress the slimes by buddles alone had been the cause of great loss of tin hitherto.

Mr. Bolitho mentioned that Mr. Brunton had invented many years ago a very ingenious separator for the purpose of sizing the particles of stamped tinstuff, by letting them fall through a column of water in a tube of about 10 feet height, placed over a travelling trough which was divided into a series of compartments or cells, so that as the trough travelled onwards the cells were brought successively under the orifice at the bottom of the tube. The largest grains falling most rapidly through the column of water reached the bottom first, and found their way into the first cell; and the trough travelling forwards, the next size fell into the second cell, and so on; the trough was of an annular form, and made one revolution for each charge of tinstuff supplied into the tube. A separator on this construction was put to work at the time at Tincroft, but though very beautiful in theory it did not answer in practice, although he believed it might yet be improved upon so as to be practically successful. The idea had originated at the tin-smelting works of his own firm, where it was felt to be very desirable to devise if possible some means by which the copper mixed with the commoner quality of tin could be separated from it. Mr. Brunton believed that the mixture was mechanical and not chemical, and suggested a plan for effecting the separation by means of centrifugal action, taking advantage of the difference between the specific gravities of metallic copper and tin, the former having a specific gravity of 8·9 and the latter of 7·3. A horizontal cast-iron pipe, about 3 or $3\frac{1}{2}$ inches diameter and 9 feet long, closed at the ends, was mounted at the centre upon a vertical axis, and having been heated red-hot was filled with the liquid metal through a hole

at the centre; it was then whirled round at a very rapid rate over a fire, so as to keep it nearly red-hot all the time. When the process was over, it was found not only that the bulk of the copper was at the extreme ends of the pipe, but that it had even forced its way through the pores of the solid cast iron, whilst the purer tin was nearer the centre of the pipe. This proved clearly that Mr. Brunton was perfectly right, and that there was a portion of the copper in mechanical union with the tin. The experiment answered very well, but the operation could not be carried out on a large scale. In consequence of that experiment, what were known as Brunton's separators for sizing tinstuff were introduced, the idea being that particles of different sizes would fall through water at different speeds, though of the same specific gravity; but the difficulty was that there was such a great variety not only of sizes but also of specific gravities. A piece of a certain size, for instance, having a specific gravity of 5, would fall as rapidly through the water as a piece of half the size having a specific gravity of 7. This it was which still constituted a difficulty in dressing tin ore, from the smaller particles of tin being washed away in the slime instead of being deposited. If mechanical engineers could help the tin dressers to surmount this difficulty, they would render Cornwall a great service. Some means must be devised by which the whole of the tin that was raised from the mines in Cornwall might be utilised by those who raised it; and unless further improvements were made that would accomplish this object, he believed very many of the mines of the county must sooner or later be abandoned.

The CHAIRMAN observed that the principles involved in the dressing of tin ore were the same that had been successfully applied in other matters. For instance, there were various purposes for which currents not of water but of air had been utilised to effect separation. One of these was in the preparation of beaver fur, when hats were really made of that material. The covering of the skin of the beaver was composed partly of the fine fur and partly of a coarse hair; the knife of necessity cut these two substances

off together, and the first step in the manufacture was to separate them. This separation of the beaver from the hair was effected by putting the material into a closet, through which an upward current of air was made to pass; a slide was then pushed across about midway in the height of the closet, and the current being stopped, the beaver was found above the slide, while the hair remained below. Reverting to the immediate subject of the paper, it appeared to him that the dressing of tin slimes offered an excellent opportunity for the employment of a current of air, as the dressing of this material by air would be closely analogous to the case of grinding corn by millstones, where a current of air was used between the stones to separate and carry off the fine flour directly it was ground, and so prevent it from being overground. The illustration that had been given of the opposing influences of size and specific gravity of different substances was clearly correct; for a piece of gold, for instance, notwithstanding its high specific gravity, would if beaten out into the form of gold leaf be easily blown away by a current of air which would not stir a large stone, though of much lower specific gravity. The reason why larger pieces of matter of lower specific gravity descended more quickly through a resisting medium than pieces of higher gravity but of smaller size was clearly that, whereas the contents decreased as the cubes of the dimensions, the surfaces acted upon decreased but as the squares; therefore it was only necessary to go on reducing the size of a substance, no matter how ponderous, until its contents got sufficiently small in relation to its superficial area, in order to reach a point where the effect of extent of surface would take precedence over the influence of specific gravity. If it could only be managed to get particles all of the same size, then indeed their specific gravities would come into play, and their separation would be easily effected; or the same would be the case if they were all of the same specific gravity but of different sizes. The difficulty was to deal with particles of dissimilar sizes and gravities when mixed together as in the stamped tinstuff.

He moved a vote of thanks, which was passed, to Mr. Ferguson for his valuable paper, in which it was shown how the apparently

hopeless problem was accomplished of making a profit out of a material containing only 1 or 2 per cent. of saleable produce. He hoped mechanical engineers would turn their attention to the improvement of the tin-dressing processes; they had always been ready to meet any demands made upon their ingenuity, and he had no doubt it would be so in the present instance.

The Meeting was then adjourned to the following day.

In the afternoon an Excursion was made by the Members from Penzance by special train and steamboat to Penryn, Falmouth, Restronguet, and Truro.

At Penryn the Granite Works of Messrs. Freeman and Sons were visited, where the application of machinery to various processes of stone dressing was seen in operation. The shaping of columns, balustrades, and other stonework of circular section is done by turning in a lathe, the work having previously been roughly dressed to shape by hand labour and centred in the lathe. The turning tool, instead of being a fixed tool as in turning wood or metal, consists of a freely rotating circular disc of the hardest tempered steel, about 9 inches diameter, mounted upon a horizontal axis in the slide-rest, and held up obliquely with its edge against the work in the lathe, so that the work revolving causes the tool to revolve in contact with it, and the cutting edge of the disc flashes off continuously small particles of the stone. In the case of the best descriptions of work, the lathe is used only for roughing out to the true circular form, and the work is afterwards dressed finally by hand labour to take out the tool marks. The smoothing and polishing of the granite is done by means of cast-iron rubbers, which in the finishing process are faced with flannel. The smoothing is done with sand and water, the sand being fed in by hand by the attendant; and the polishing is done in the same way, first with

emery powder and water, and afterwards for finishing with putty powder and water. The work done upon the premises at Penryn is mostly of an ornamental description for architectural, monumental, and other purposes; and the stone employed is principally grey granite, very hard and close-grained, which is supplied from a large number of quarries in the neighbourhood of Penryn; red granite from Dartmoor is also worked, and another variety of grey granite from Lamorna quarry near Penzance. Ordinary plain stones for building purposes, dockworks, &c., are dressed by hand labour at the quarries; complicated shapes, such as those having a curvature in two directions, are executed at the works in Penryn.

From Penryn the Members proceeded to Falmouth, where they were entertained at luncheon in the Polytechnic Hall by the invitation of the Royal Cornwall Polytechnic Society. They were then conveyed by special steamboat from Falmouth Docks to the Restronguet Tin Stream Works (a description of which forms the subject of a paper read at the Meeting), where the propeller knife buddle and Collom's self-acting jigging machine described at the Meeting were seen in operation. From Restronguet the Members proceeded up the river to Truro, and returned from there by special train to Penzance.

The Adjourned Meeting of the Members was held in St. John's Hall, Penzance, on Wednesday, 30th July, 1873; FREDERICK J. BRAMWELL, Esq., F.R.S., Vice-President, in the Chair.

The following paper, communicated through Mr. Richard Taylor, was read :—

DESCRIPTION OF THE TIN STREAM WORKS IN RESTRONGUET CREEK NEAR TRURO.

By Mr. CHARLES D. TAYLOR, of Devoran.

The object of these works is to recover a valuable deposit of Stream Tin which is found under the water in Restronguet Creek, and lies on the rock beneath the mud and silt that form the bottom of the creek. "Stream Tin" is the name given to the tin ore found in diluvial beds, which is usually of very superior quality to that worked from lodes; the best stream tin consists of pure crystals of oxide of tin called "black tin," worn round by the action of water.

The Carnon Valley, which has its outfall in the Restronguet Creek, was in the last century the site of one of the most important stream works in Cornwall; and the old streamers followed the tin bed some way down into the creek, keeping out the tide by means of large embankments, of which a great part still remain, and removing the whole of the overlying silt to get at the tin. The tide having broken in over the embankment about the year 1800, the works were then abandoned; but about 1822 the working of the tin bed was resumed by mining under the silt of the creek, and this was successfully carried on for about five years. Some time later a lower part of the creek was similarly worked, beyond the present working, and operations were continued until 1843; the remains of this working are still to be seen in the old mine island in the middle of the mouth of the creek.

In 1871 the present operations were commenced for working the portion of the tin bed known to remain unwrought between the two old mines. Both of the old workings had been much troubled with water, the levels not being always deep enough to drain the dips in the rock; it was therefore decided in the present workings

to drive a deep main level in the rock at $4\frac{1}{2}$ fathoms depth below the tin bed, to act as a drain for all the water, and as a tramway level for removing the stuff. A plan and section of the workings are given in Figs. 1 and 2, Plate 58, showing the deep level in the rock at A A, and the tin bed at B B.

On trying the ground by boring, it was found that the cover over the tin bed consisted generally of about 60 feet thickness of mud with some sand, and the tin bed beneath was from $1\frac{1}{2}$ to 4 feet thick, resting directly upon the rock. In the trial borings it was at first intended to bore holes of 5 inches diameter; but these were not attempted, because it was found necessary to have iron tubing the whole depth, and the suction of the mud on the sides of tubes of that size made it extremely difficult to draw them up after the holes were finished; the smaller size of 3 inch tubing was therefore adopted, and although the samples of the tin bed obtained from holes of this size were necessarily small, they were sufficient for the required testing of the quality of the bed.

The workings were then commenced by sinking the shaft C on the beach below high-water mark, the tide being kept out by solid 9 inch square timbering built up from the rock round the shaft, with a wall of oak faggots round it, and 3 feet of puddle between, made from the mud of the creek. The shaft was sunk through the rock to a total depth of 18 fathoms from the surface; and the deep level A A was driven out to the middle of the creek, 9 feet high and 5 feet wide, with a tramroad laid in it. An engine was required to pump out the water, which came mostly from the land side and not from the creek; and the tramroad was laid $2\frac{1}{2}$ feet above the bottom of the level, so as to form a reservoir beneath, in which the water could be allowed to accumulate to that depth without interfering with the road, in case of the engine ever stopping for a short time.

An iron shaft D was also sunk at the same time in the middle of the creek for securing good ventilation of the workings. It was sunk in a bank of soft mud, covered 10 or 12 feet with water at high tide, a staging being made by piles driven 12 feet into the mud, and supported from sinking by cross timbers bolted to the piles just

below the surface of the mud. The shaft was constructed of cast-iron cylinders, 6 feet diameter, 6 feet long, and $1\frac{1}{4}$ inch thick, put together with internal flanges faced in the lathe. Each length weighed about $2\frac{1}{2}$ tons, and was lowered by a crane through an opening in the stage, between guides to keep it true in position. The first length was made sharp at the bottom edge for entering the mud, and was sunk into the mud by the weight of two more lengths fixed upon it; the core was then cleaned out, and further lengths were forced down by pressure from the chain of a crab-winch, and afterwards by the weight of barges loaded with stone and made fast at high tide to a girder across the top of the shaft, so that their weight came on the cylinder as the tide fell. The cylinder was thus sunk to the tin bed without much difficulty; during the sinking, the core was always cleaned out rather below the bottom of the cylinder before the barges were attached, and if left for a day the mud was found to swell up three or four feet into the cylinder. A total weight of about 250 tons was required to sink the cylinder as it neared the tin bed, which was about 3 feet thick at this part. Altogether thirteen of the 6 feet lengths of cast-iron cylinder were sunk, making the total height of the iron shaft 78 feet. The top of the shaft is 8 feet above high-water mark, and 4 feet above the top of the engine shaft C; the iron shaft thus forms the upcast in the ventilation of the mine, and the difference of 4 feet in the height of the two shafts is found sufficient to maintain thorough ventilation throughout the whole of the workings by natural means alone, without the need of resorting to any artificial methods for the purpose.

The iron cylinder was only sunk to the top of the tin bed, and the sides of the shaft were timbered below, leaving two openings opposite to each other, through which levels were driven east and west towards the shore on either side of the creek, to prove the width of the tin bed; there was found to be about 18 fathoms width of unwrought ground, left between old workings where the tin bed had been removed on each side of the creek. Two parallel levels E E, 20 fathoms apart, were then driven in a northerly

direction up the creek, nearly at right angles to the first, and have been extended for about 90 fathoms length. These serve as the basis for the workings; a tramroad is laid in each, and a communication is made from the southern extremity of each to the deep level A A below, by passes or shoots F F, which are made double, one half for the tin gravel and the other for waste. Air levels G G are driven at right angles between the two main levels E E at every 20 fathoms, and are extended on each side beyond the main levels as far as the tin bed continues productive, the widest part yet proved being 50 fathoms; and cross or "stripping" levels H H are driven about 14 feet apart from one air level to another. The men get to the workings at low water by the centre iron shaft, and at high water from the deep main level by a ladder through one of the passes.

All the levels have to be strongly secured with timber, as the mud soon begins to crush very heavily; and in the two main levels E E a frame or "set" is fixed at every $2\frac{1}{2}$ feet, consisting of a pair of legs made of 8 inch Norway balk, sloping inwards from $4\frac{1}{2}$ feet opening at bottom to 2 feet opening at top, with a 10 inch Norway cap piece, and covered in with "laths" made of half logs on the top and $1\frac{1}{2}$ inch planking at the sides; in the air levels and stripping levels the sets are smaller and further apart. In some places the mud crushes down much more than in others, and it has been necessary to replace many of the sets, though the adjoining ones remain uninjured; but a set is easily replaced when broken, as the mud does not fall suddenly, but gradually swells down, allowing ample time for the repairs. The bottoms of the levels are generally sunk one or two feet into the rock, and the legs of the sets rest upon the surface of the rock on either side of the level.

In "stripping" or removing the tin gravel, as has now been done throughout the extent of the shaded portions J J in the plan, Plate 58, the side laths are taken out between two sets, which are 3 feet apart in the stripping levels, and the tin gravel is removed for 7 feet width on each side. The same is then done in the next space, and the intermediate set left entirely free; this is then removed by cutting away the rock under the legs, leaving the roof laths supported at one end by the next set, and these are left to

come down gradually with the settling of the roof, and serve to close up the end of the level and keep out the mud. Whilst stripping each space, temporary props are put in at the sides, which are removed when the stripping of the next space begins. This process is continued, removing each set in succession, and removing also the roof laths as they are left free, until arriving within 9 feet of the air level, when the end is securely breasted up; and after all the stripping levels have been worked out to the same extent, the air level itself, if no longer required to be kept open, is also stripped back in the same manner. After the stripping of the cross levels, the timber of the air levels G G becomes severely crushed, notwithstanding the 9 feet of gravel left on each side to support the roof; but the sets of the stripping levels are generally got out uninjured, and ready for use again. A width of 30 feet of gravel is left on each side of the two main levels E E, as it is of so much importance to keep these open. No mud is taken away in stripping, but it is allowed to fall, and soon fills up the space from which the gravel has been removed. The whole of the tin gravel is completely cleared out in stripping, the floor and roof of the bed being everywhere quite definitely marked; and every stripping place is examined after the gravel has been removed, to ensure its being entirely cleared before the mud comes down.

The bed of tin gravel is sometimes 6 or 7 feet thick, and the men are then able to stand up to work; but more often they have to lie down when stripping, and sometimes where the bed is very thin they have to cut away some of the rock to enable them to reach in far enough. The mud when fresh broken is nearly black, and is dry and very tough; but after exposure to the air it becomes a light brown colour, and much softer and moist. Gas is given off by the mud and tin bed, which has on two occasions been found to take fire; and when the mud begins to fall it exhausts the air very fast, and on that account one party of men have the stripping of two or three levels in hand at the same time, changing from one to another as the air may change from better to worse. Sometimes, notwithstanding a good current of fresh air passing across the mouth of a stripping level and partly entering it, a candle will not keep alight near the falling mud, but gradually

goes out, on account apparently of the absorption of oxygen from the air by the mud, and probably also the evolution of carbonic acid gas from decomposition of the mud, which contains a great deal of organic matter. When exposed to the air the mud swells considerably, in consequence the writer believes of its containing a quantity of protosulphate of iron, which by absorbing oxygen from the air becomes converted into persulphate and oxide of iron.

The workings in the tin bed are quite dry, with the exception of the ends of the two main levels E E that are being driven up the creek, where there is a little water coming in from the rock in the bottom of the levels; not a drop of water finds its way through the mud, although at high tide there is a depth of 12 to 14 feet of water overhead. At that time the greater pressure upon the timbering of the levels is very perceptible. There is a good deal of water in the deep level A A in the rock; and the pump, a 15 inch plunger with 4 feet stroke, has to make from 7 to 8 strokes per minute to drain it.

The stuff from the strippings is wheeled in barrows to the tram wagons in the main levels E E, and conveyed to the passes F F at the end of these levels, where it can be stored to the extent of about 10 tons of tin gravel and 10 tons of waste in each; it is let out by a shoot into a tram wagon in the deep level A, and the wagon with its contents is drawn up the engine shaft C in a cage. The waste is tipped on a heap at the water side for ballast, and the tin gravel is conveyed to a pass over the dressing machinery, where it is first raked out upon a grate on which a stream of water falls, and is washed to separate the small stuff from the large stones; the small is washed through the grate into a pair of revolving screens or sizing trommels. The fine stuff that passes through these trommels is washed into the Slime Separator shown in Figs. 3 to 5, Plate 59, consisting of a box or hopper K with sloping sides, which has a small hole at the bottom, opening into the horizontal pipe P; one end of this pipe is supplied with water from a cistern overhead, and the stuff delivered by the launder L into the hopper K is met by an upward current of water entering through the bottom hole, whereby the slime is floated off into the side launder M, while the heavier portion of the stuff falls through the hole into the horizontal pipe P,

from the open end of which it is delivered to one of a pair of Collom's jigging machines. The pipe P is provided with a couple of stop-cocks N N, by which the flow of water is so regulated that the quantity rising into the hopper K and flowing over into the side launder M shall be sufficient to carry with it all the fine slimes, but yet allow the sand and gravel to fall through into the pipe and be washed on to the jigger. The slime of the stuff as it comes from underground at Restronguet contains no tin, and is allowed to run away. A pair of these slime separators are employed to supply a pair of Collom's jiggers (Plates 55 to 57), in which the stuff is separated by continued agitation in a stream of running water, causing the earthy matter to be carried away by the stream, and leaving the heavy tin ore at the bottom of the settling boxes or "hutches." By one operation the whole of the tin in the stuff supplied to the jiggers is thus saved, and 95 per cent. of the waste is got rid of, the stuff as it goes to the jigging machines containing only about ½ per cent. of tin ore. The tin from the first jigging machine is washed twice in a propeller knife buddle (Plate 45), and is thereby rendered fit for market. No manual labour is required in attending the jigging machines, except for removing the waste and tin as delivered from them; and the buddle simply requires the attendance of a boy to throw the stuff in, and can easily be made entirely self-acting.

The large stones that do not pass through the grate in the first washing process are picked over by hand, and those likely to contain tin are saved for stamping. The coarse stuff that will not pass through the trommels in the second process is jigged in an ordinary jigger worked by steam power, and part of the tin obtained from it is fit for sale without stamping, but the greater part requires stamping.

The tin bed varies much in thickness and in productiveness; in some places it is as much as 7 feet thick and in others only 3 inches, and the produce varies from 15 per cent. to only 1-10th per cent. of black tin (oxide of tin). The top of the bed is generally nearly level, so that as the surface of the rock below rises or falls the gravel is thinner or thicker. The bottom of the bed is generally much the richest in tin, but there is sometimes a second floor of tin

above, richer than that below, and having a different quality of waste associated with it, as if deposited at a different period. Some of the boulders found in the bed weigh as much as 3 cwts. In the old workings, and also recently in the new, some fossil remains of stags' horns and bones &c. have been met with; and in washing the tin several small particles of gold have been found, some of nearly 4 grains weight, and some much larger nuggets of gold are stated to have been found in the old workings; gold is very generally found in small quantities with stream tin. The mud immediately over the tin bed is often full of shells, some in good preservation; and in driving one of the two main levels E the trunk of an oak tree was met with, and had to be cut through; it was sound and tough, though soft, and was quite black throughout.

Mr. Richard Taylor said the Restronguet Tin Stream Work described in the paper might be called a submarine stream work, being carried on beneath an estuary that was filled by the sea at high water; and all that had been done there had been performed under the direction of his son, Mr. Charles D. Taylor, who was the engineer of the work. The greater number of the valleys in Cornwall had been worked in old times for what was called stream tin, that is, the tin gravel which was found lying in the bottoms of the valleys almost universally throughout the county. The mode of working was by pits and trenches; and there still existed in the wilder parts of the county remains of ancient workings of this kind where the surface of the ground had been so extensively turned over as to prove that a vast amount of labour must have been employed upon them; probably it was the tin obtained in this way that rendered the county so famous in very ancient times. The streaming of most of the great valleys and their tributaries was continued by the old streamers until they reached the tide; and in Restronguet Creek it had been carried on by them still further, by banking out the tide, and diverting the two confluent streams that

came down the two valleys into a side channel cut for them in the face of the rock on the western side of the creek. Then the overburden of the large tract thus reclaimed from the tide was removed, although very considerable in amount, and the tin gravel beneath was won. At the present time the removal of a large amount of overburden of that kind would hardly present any considerable difficulty; but considering the limited nature of the mechanical appliances that were available at the latter part of the last century, when this work was accomplished, he thought it might fairly be said that the adventure was a very bold one. It was however a very successful one, laying the foundation of some fortunes and adding greatly to others of families well known in Cornwall. The operations were continued until nearly the whole of the tin within the area embanked had been worked out; but before the lower limit of the embankment was quite reached, a great storm occasioned a very high tide, which broke through the dam and filled the whole of the workings. Nothing further was then done until some forty or fifty years ago, when work was resumed in the creek, not by embanking as before, but on a plan similar to that now carried out at the works described in the paper. A shaft was sunk in the rock on one side of the creek, above the site of the present operations, and a level was driven out from it towards the middle of the channel, whence other levels were driven in the tin ground. The adventurers made considerable profits for some years he believed, until at length owing to unfortunate disputes the whole undertaking was abandoned. Another attempt was subsequently made lower down the creek, below the present works; but though successful in a mining point of view, the low price of tin at that time rendered it unprofitable, and this adventure also was abandoned. As it was known that between these two last workings there lay a large extent of tin ground which had not been touched, the present workings had been commenced at that point; and the shaft sunk in the rock by the side of the creek had been carried down deeper than in the previous attempts, so as to have the main level driven in the solid rock, instead of in the tin gravel where it would have been exposed to the difficulties necessarily attendant upon working in such insecure ground. This level was accordingly driven from 4 to $4\frac{1}{2}$ fathoms

below the top of the rock, to communicate with the iron shaft sunk in the middle of the creek, and was then continued for some distance further across the known run of the tin ground, after which it was turned somewhat in a northerly direction to run up the creek, and would be carried on as the main road up to the furthest boundary of the ground to be worked. This plan of having an independent level driven in the rock, totally distinct from the levels constituting the workings in the tin gravel, ensured the maintenance of complete ventilation without any mechanical appliances or ventilating furnace; and it also afforded great convenience for bringing away the stuff from the workings, which had merely to be tipped down through the passes from the upper working levels in the tin gravel to the lower level in the rock, along which it was then conveyed in trams to the engine shaft, and hoisted to the surface. This was the first instance in Cornwall where the stuff broken in a mine was drawn through a perpendicular shaft to surface in the same trams which conveyed it along the levels to the shaft. Hitherto in the Cornish mines the stuff had always been raised in kibbles or skips, and tipped into wagons on arriving at the surface; and although the other plan was in general use at collieries, there were very great difficulties in the way of its adoption in most of the Cornish mines, where the stuff had to be drawn from a great number of different levels and in very irregular quantities. In the particular instance of the workings at Restronguet however, which bore a greater resemblance to colliery workings than to those of ordinary Cornish mines, it was obvious that the plan adopted was the proper one, all the stuff having to be drawn from the same depth.

The tin gravel brought up in the tram wagons was tipped upon a grating, and washed by a strong stream of water; being embedded in a very stiff clay, almost as stiff as what was called London clay, it required more sluicing and washing than was the case with tinstuff coming from lodes. All that fell through the grating was then taken to the revolving sieves, or "trommels" as they were called in Germany; and the larger stones which were delivered from the lower end of the trommels were taken to the picking table to be hand-picked according to their quality, while

the smaller stuff that passed through the meshes of the sieves was carried forwards by the stream of water to the Collom's jigger. Immediately before entering the jigger however the finest particles constituting the slime were separated and floated away by a strong current of water, to be buddled or otherwise treated separately from the coarser stuff that entered the jigger. The action of this jigger was so effective that it got rid of the greater part of the waste at one operation, the heavy tin sand passing down into the hopper beneath the sieve of the jigger. In the present instance two of the machines were used in conjunction, so that the waste discharged from the first was jigged over again in the second; practically this was found to be hardly necessary, as with stuff of that quality almost the whole of the tin was saved in the first jigging; nevertheless the second jigging was still continued, the object being to throw away no tin whatever in the waste. The tin sand deposited in the hopper of the jigger was then taken to the propeller knife buddle. This machine was new in Cornwall, the one at Restronguet being the first in the county, and it proved very effective in buddling the stuff without entailing any costly labour. With some of the sand it was found that a single passage through the knife buddle rendered it clean enough for the market; and it was never necessary to pass it through the machine more than twice. The stuff that was being washed in this buddle was solely the natural sand found in the clayey gravel; the gravel itself was laid aside to be stamped by the pair of pneumatic stamps now in course of erection for the purpose. These stamps would also be employed for stamping the large stones of tin taken out at the picking table; and the whole of the stuff from the stamps would then be washed by the propeller knife buddle.

Mr. C. Cochrane mentioned, in reference to the propeller knife buddle, which he had seen at work at Restronguet, that in Maryland in the United States he had seen an excellent machine of somewhat different construction, used for dressing ironstone; the material was placed upon a slightly inclined grid, and the lighter particles were carried away by the action of a stream of water descending upon it, the ironstone being gradually pushed forwards

up the grid by a set of reciprocating rakes. The propeller knife buddle however had the advantage of working with a continuous rotation instead of a reciprocating motion; and it accordingly appeared to him a much more perfect machine for performing the dressing of ores.

Mr. Richard Taylor said, as any improvement in dressing was of such immense importance in Cornwall, he might add with regard to the propeller knife buddle that for lead dressing it was now superseding one that had been in use in Cardiganshire for some time and was there known as the Lisbon buddle, in which a series of scrapers were drawn forwards through the stuff in the buddle, and then lifted and drawn back above the stuff; that machine was ingenious but complicated, and the inventor of it, a Cornishman named Vigurs, had now invented the propeller knife buddle to supersede it. As applied to dressing tinstuff the machine at Restronguet certainly seemed to be doing its work very well. At lead mines, in dressing some ores which contained a larger proportion of waste, it had been found desirable to increase the length of the buddle considerably, so as to give more time for a complete separation. In the case of lead ores very much mixed with quartz, carbonate of lime, and other foreign substances, the effect of lengthening the buddle had been that stuff which when put into the machine contained only 3 per cent. of pure galena or lead ore was completely dressed up to 80 per cent. in a single operation, the length of the buddle employed being as much as from 14 to 16 feet.

The Chairman observed that the particulars given with regard to the dressing operations at Restronguet showed the great importance of perfecting machinery which was to be used for extracting the extremely small percentage of ore that occurred in the material as raised from the mines. He proposed a vote of thanks, which was passed, to Mr. Charles D. Taylor for his very interesting paper, and to Mr. Richard Taylor for the further valuable information he had kindly furnished upon the subject.

The following paper was then read:—

Comparative Diagrams of Buildings required for ordinary Cornish Winding Engine and for Semiportable Engine of same power.

CORNISH WINDING ENGINE.

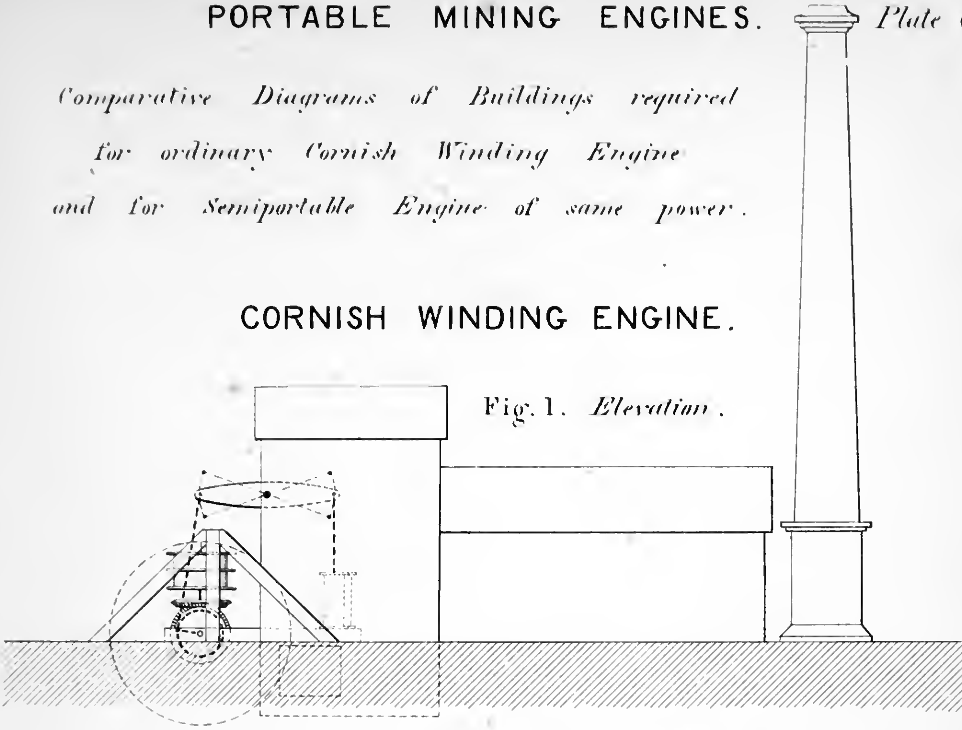


Fig. 1. *Elevation.*

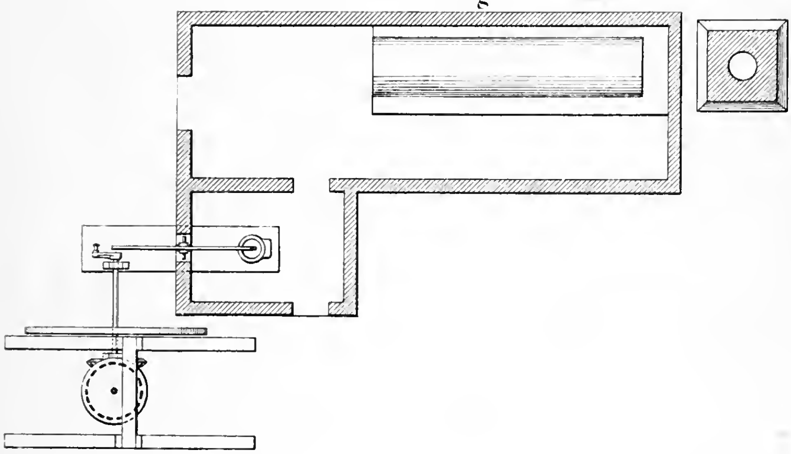


Fig. 2. *Plan.*

SEMIPORTABLE WINDING ENGINE.

Fig. 3. *Elevation.*

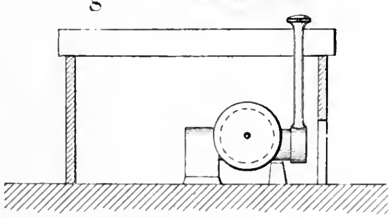
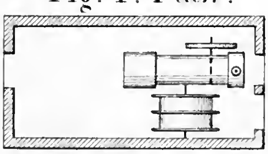


Fig. 4. *Plan.*



Scale 1/320th.

10 5 0 10 20 30 40 50 Feet.

PORTABLE MINING ENGINES.

12 H.P. Portable Winding Engine.

Fig. 5. End Elevation.

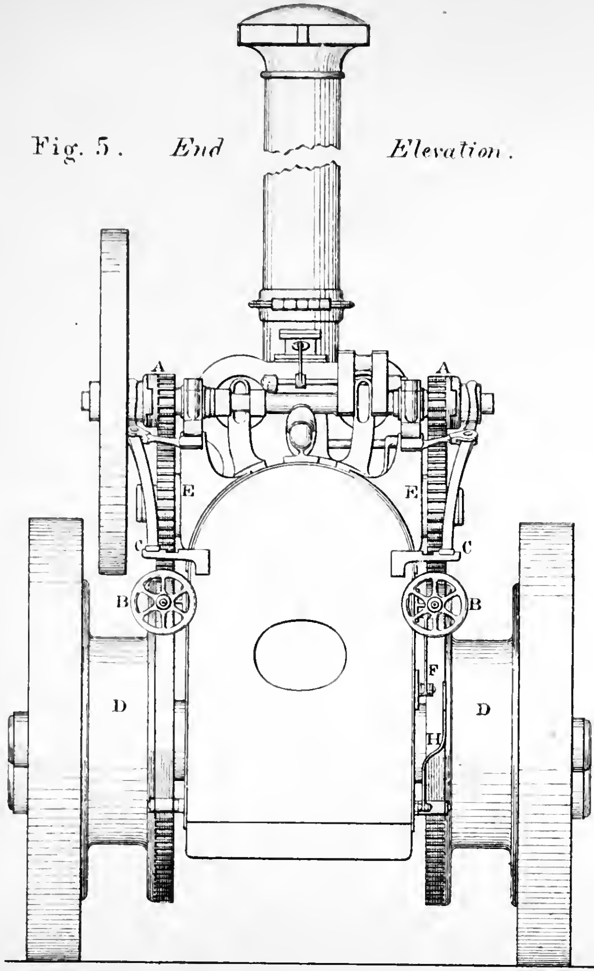
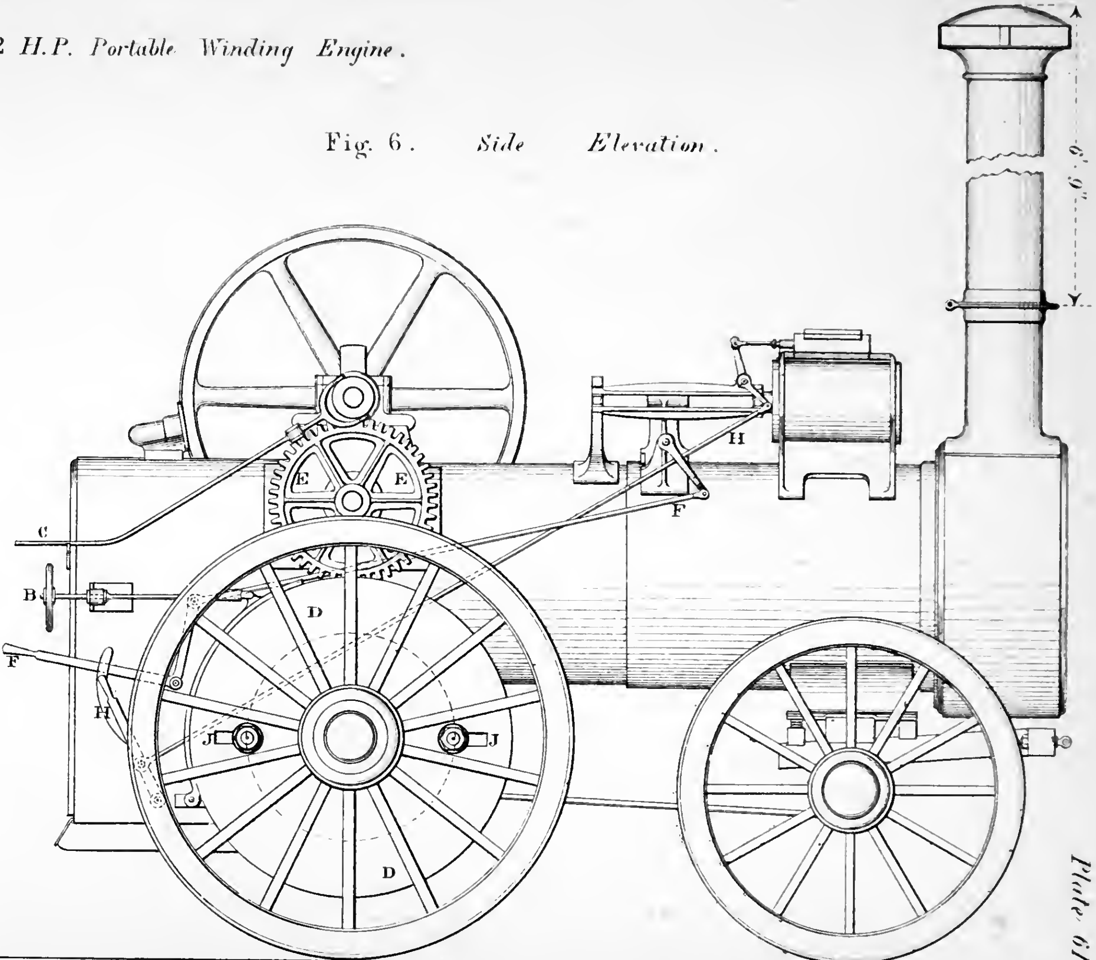


Fig. 6. Side Elevation.



Scale 1/36 th.

0 1 2 3 4 5 6 7 8 9 10 11 12 Feet.

Plate 61.

PORTABLE MINING ENGINES.

Plate 62.

20 H. P. Semiportable Winding and Pumping Engine.

Fig. 7. End Elevation.

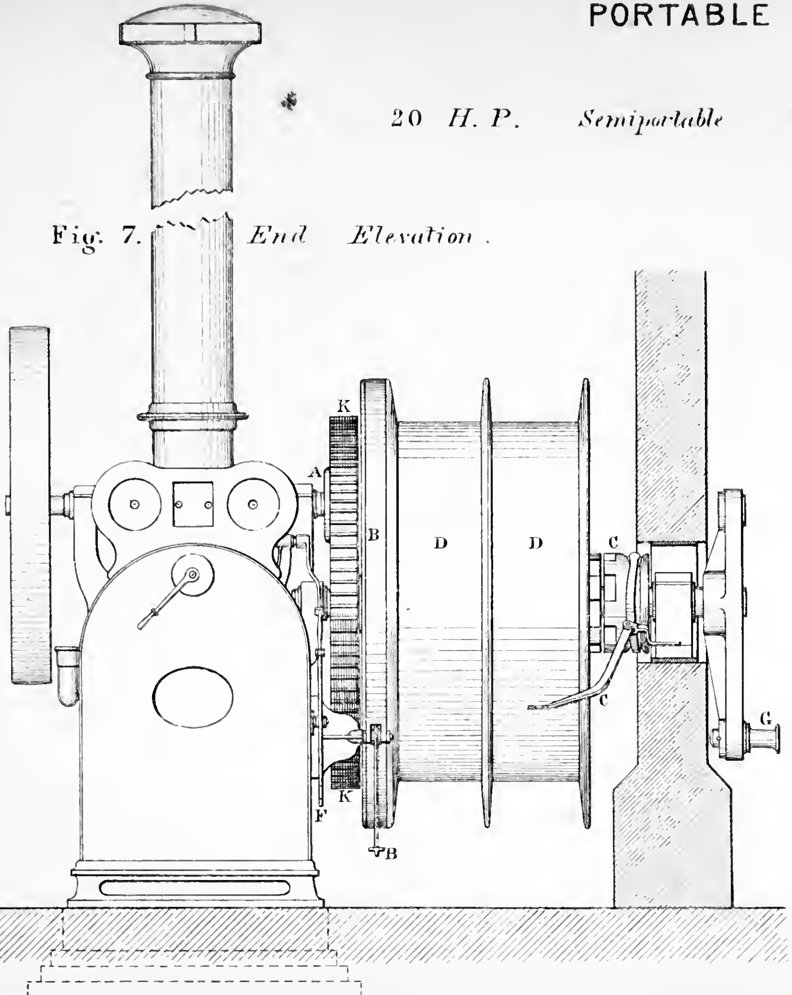
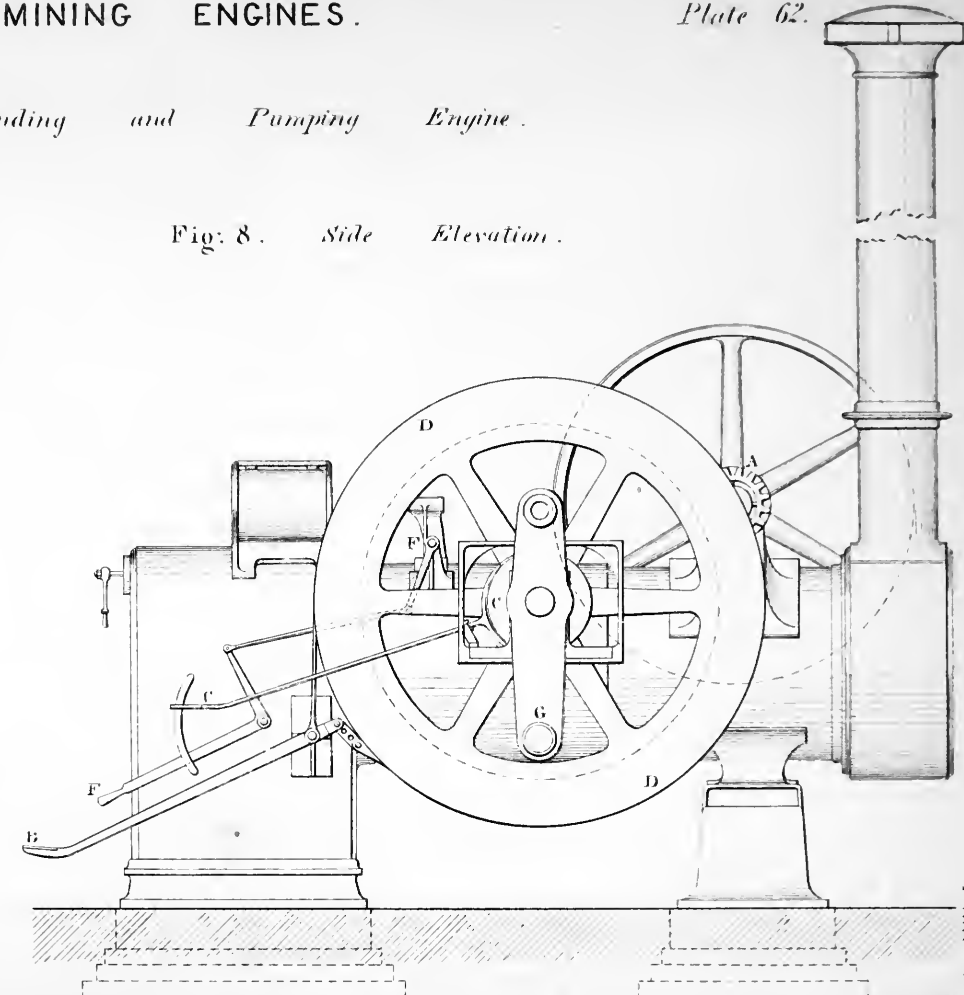


Fig: 8. Side Elevation.



(Proceedings Inst. M. E. 1873.)

Scale 1/50th.

0 5 10 15 Feet.

Plate 62.

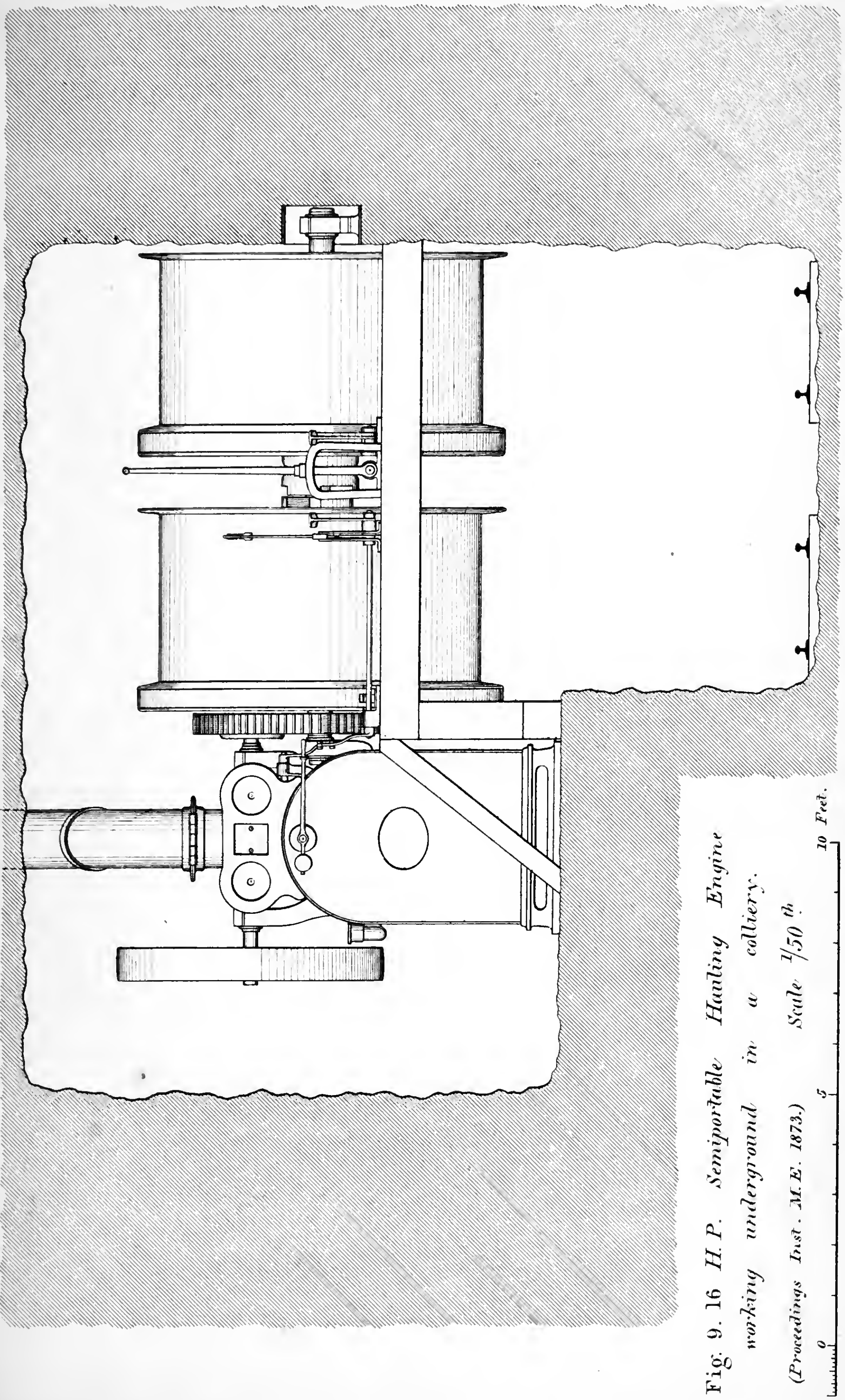
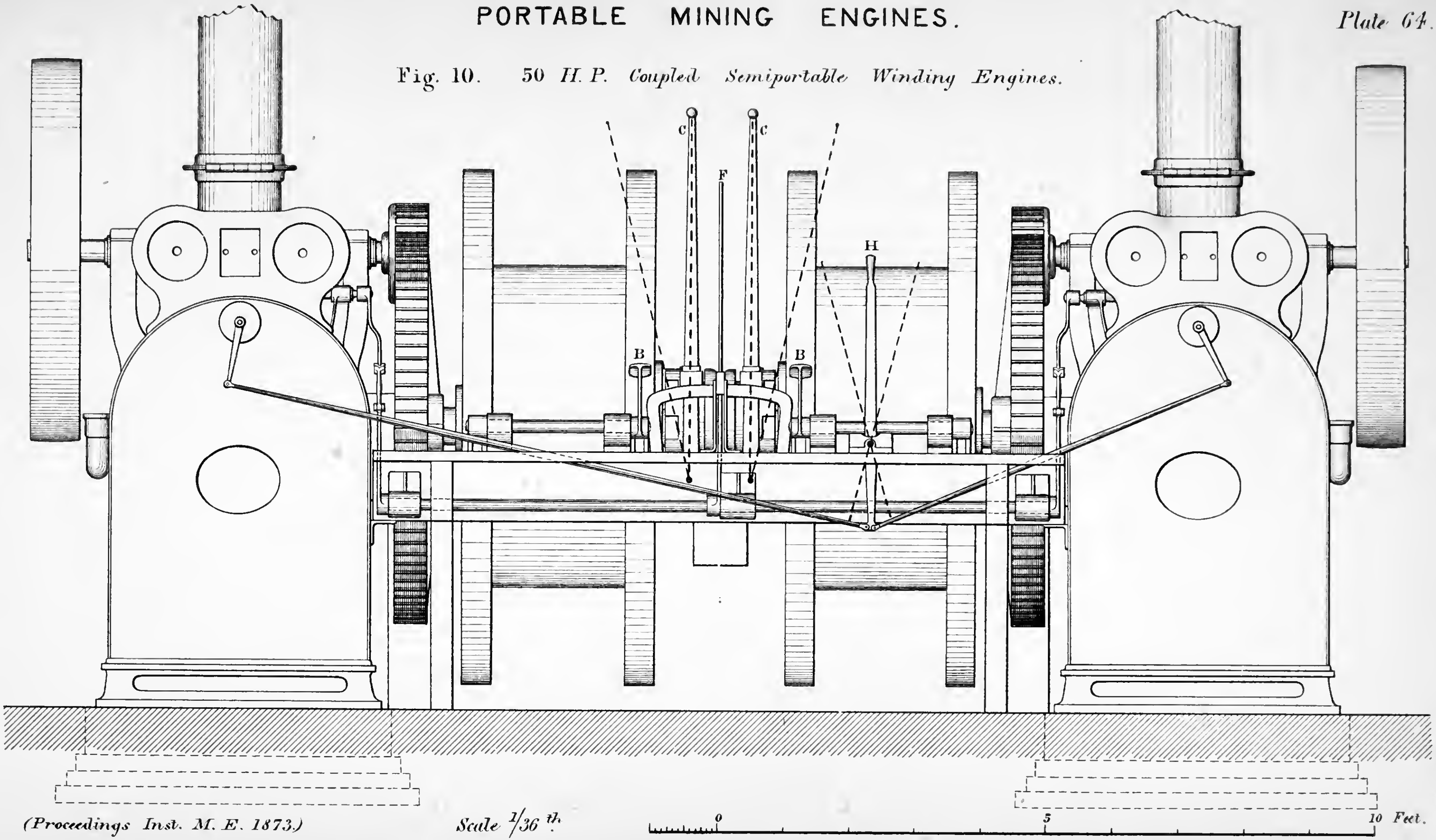


Fig. 9. 16 *H.P. Semiportable Hauling Engine working underground in a colliery.*

(Proceedings Inst. M.E. 1873.) *Scale* 1/50 th.

PORTABLE MINING ENGINES.

Fig. 10. 50 *H. P. Coupled Semiportable Winding Engines.*



Scale 1/36th.

(Proceedings Inst. M. E. 1873.)

Plate 64.

Fig. 11. *Indicator Diagrams from Semiportable Winding Engines.*

Indicated Horse Power	64·2	*and*	72·4	
Effective Horse Power	54·7	—	60·1	
Difference	9·5	.	12·3	
Percentage Loss by Friction &c.	14·8	.....	16·9	*per cent.*

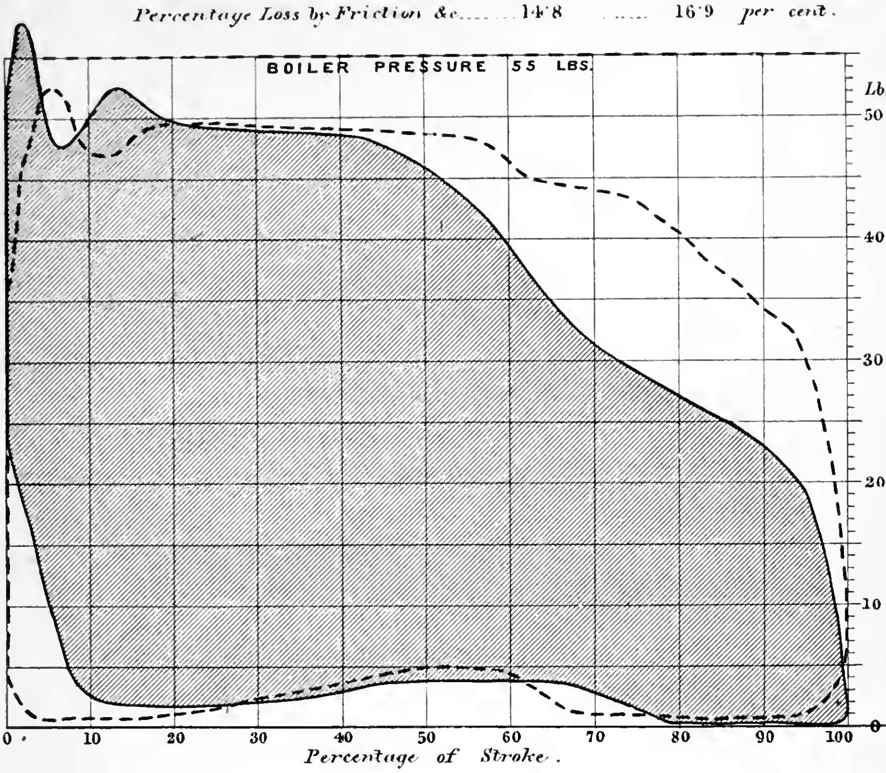
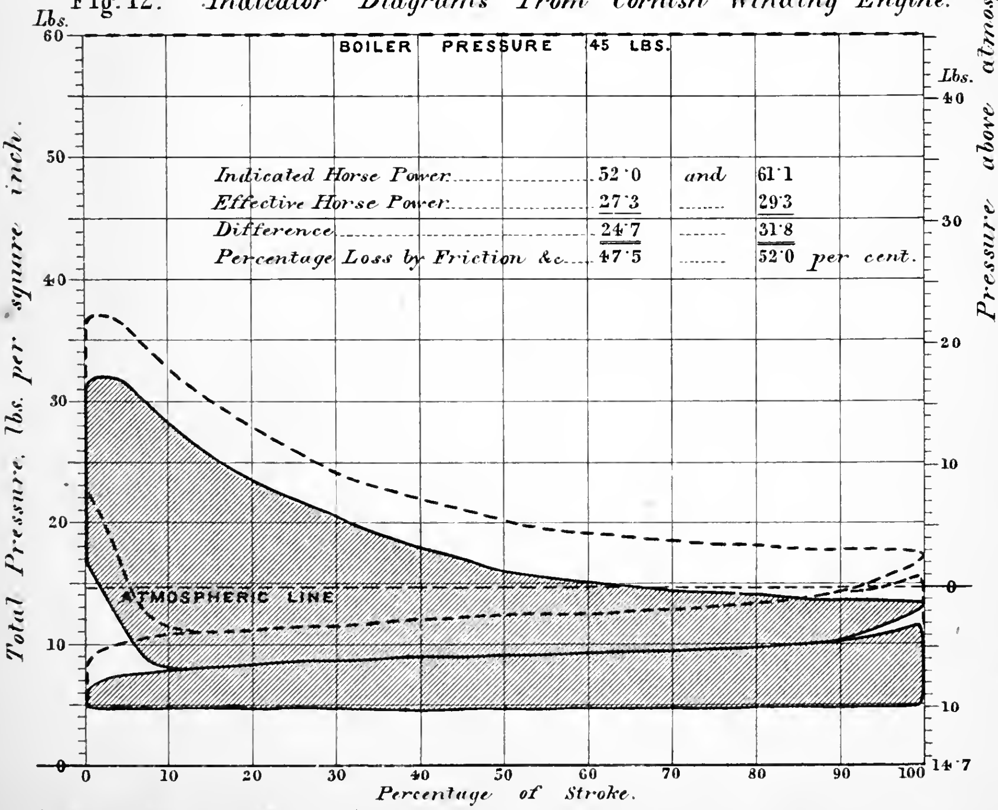


Fig. 12. *Indicator Diagrams from Cornish Winding Engine.*



Indicated Horse Power	52·0	*and*	61·1	
Effective Horse Power	27·3	......	29·3	
Difference	24·7	......	31·8	
Percentage Loss by Friction &c.	47·5	......	52·0	*per cent.*

(Proceedings Inst. M. E. 1873.)

CORNISH ENGINE DUTY. *Plate 66.*

Reported Working of Cornish Pumping Engines during 62 years from 1811 to 1872.

Fig. 13. *Duty. (Millions of foot-lbs. per cwt. of coal.)*

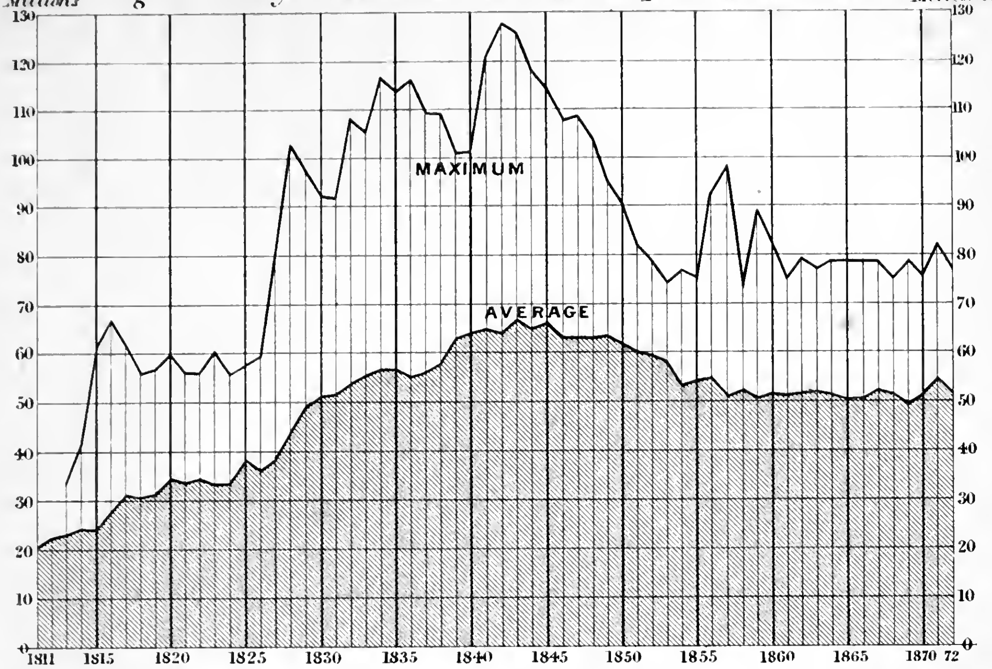


Fig. 14. *Consumption. (Lbs. of coal per Effective H.P. per hour.)*

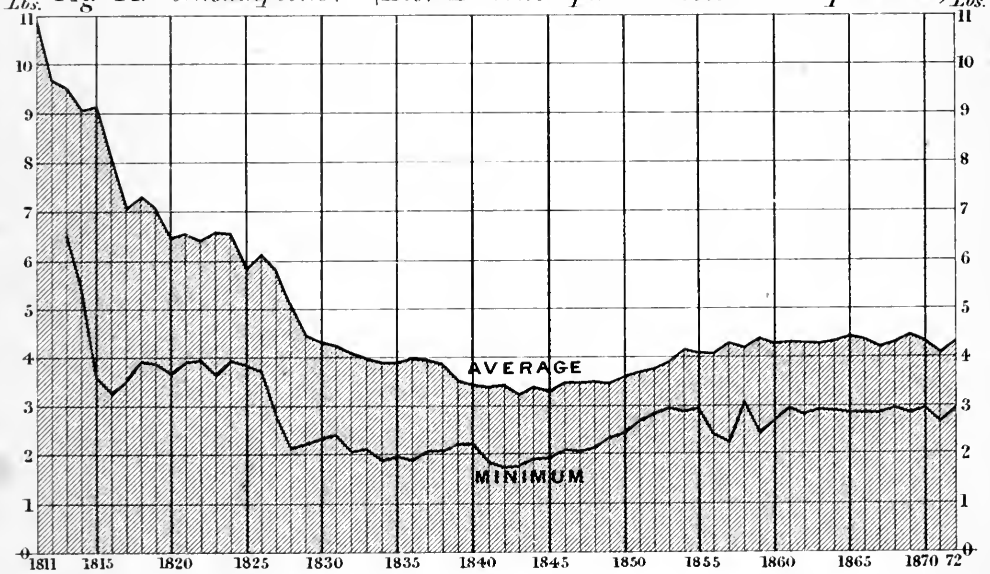
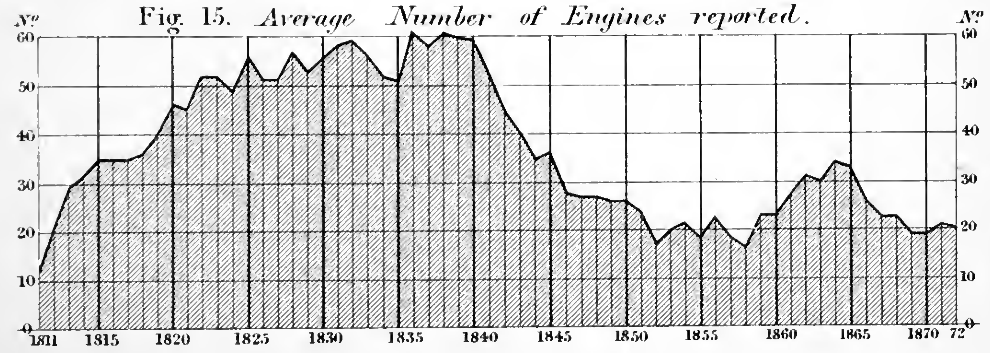
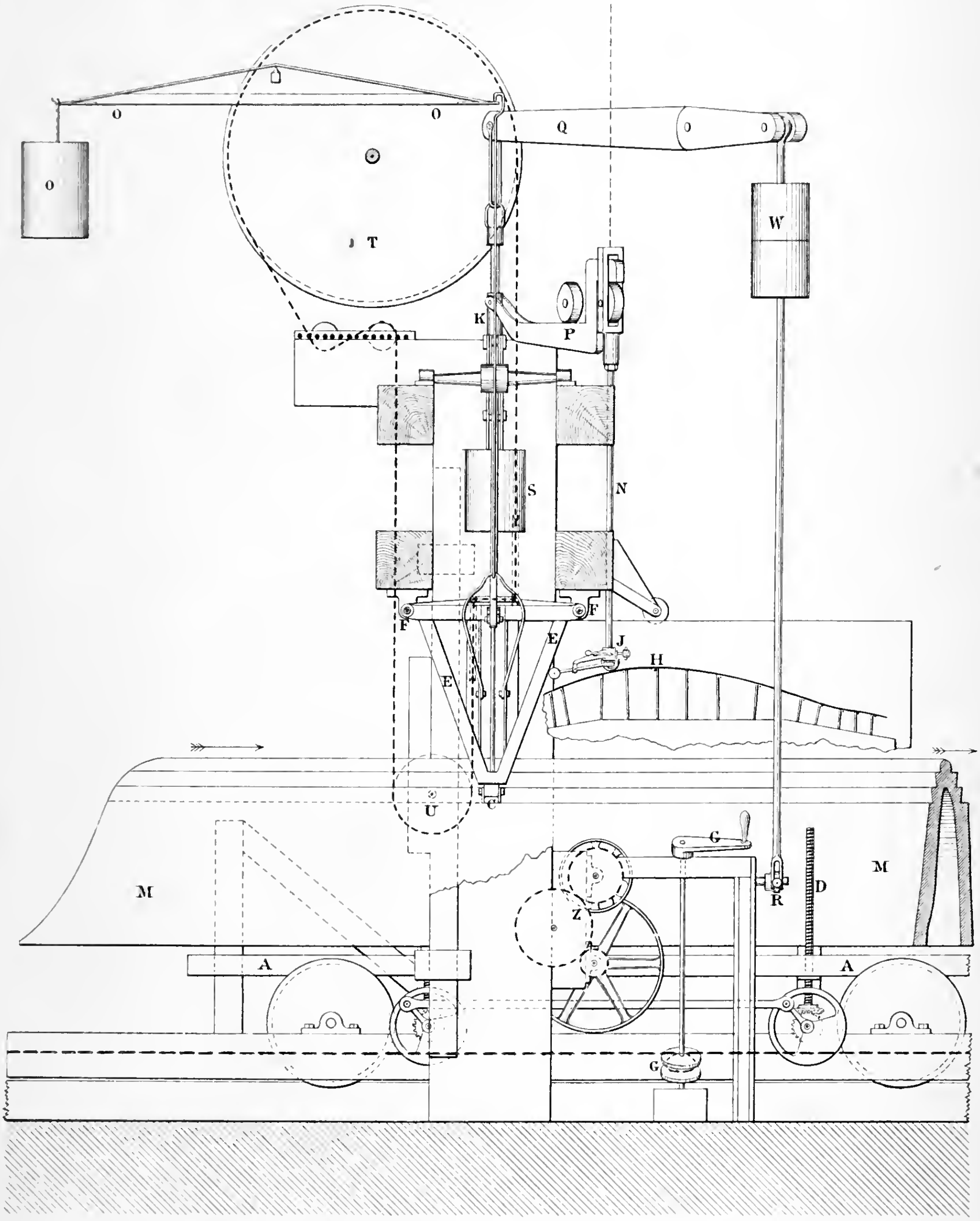


Fig. 15. *Average Number of Engines reported.*



(Proceedings Inst. M.E. 1873.)

Fig. 1. *Longitudinal Section.*



Scale 1/24th

Ins. 12 6 0 1 2 3 4 5 6 Feet.

SHIP MODEL MACHINE. *Plate 68.*

Fig. 2. *Transverse Section.*

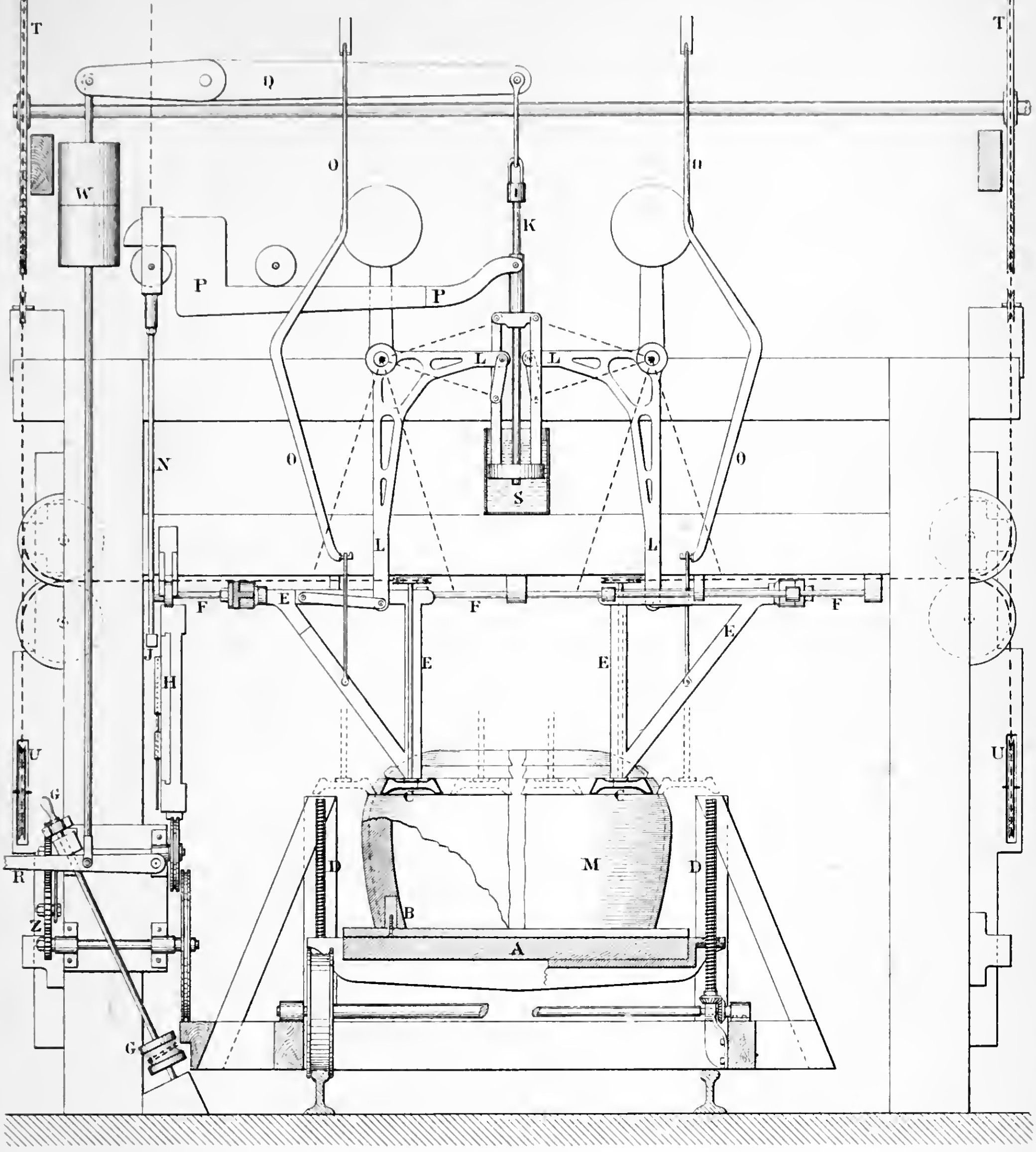
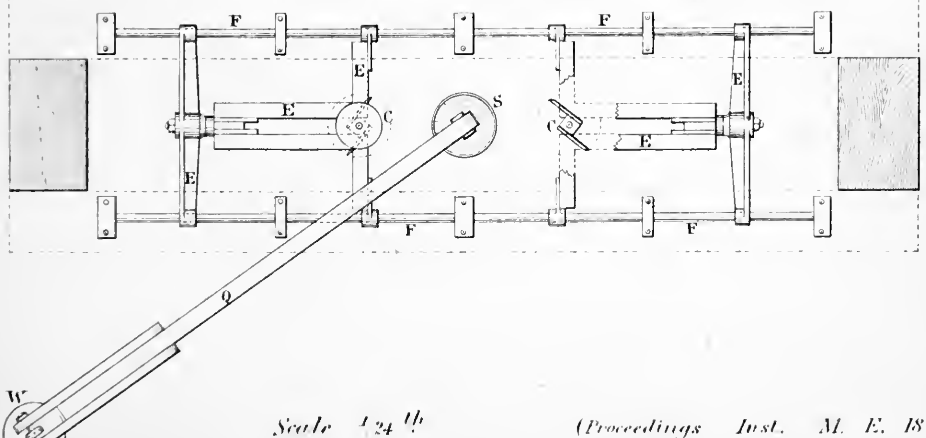


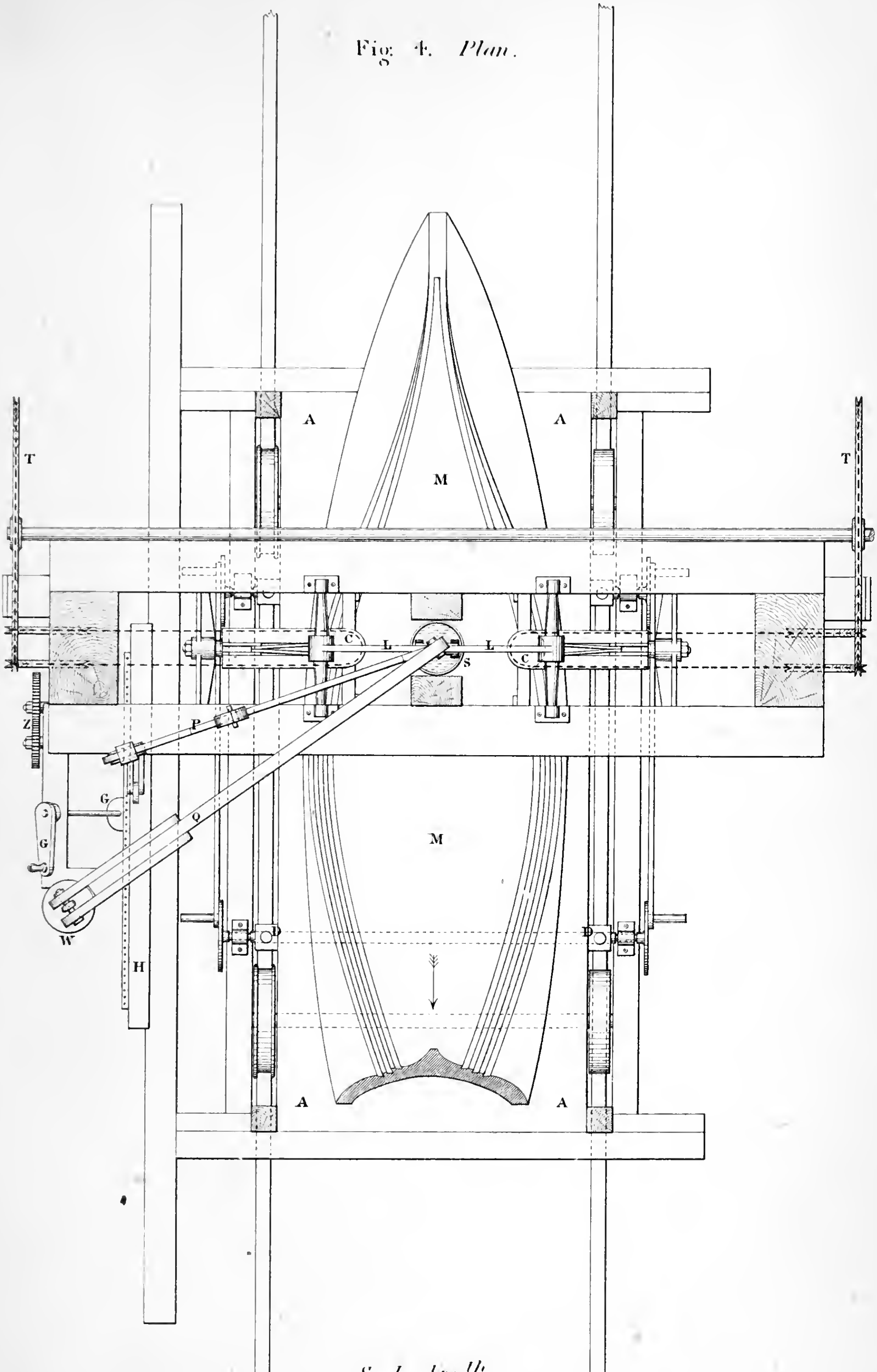
Fig. 3. *Plan of Sliding Frames carrying Cutters.*



Scale 1/24th *(Proceedings Inst. M. E. 1873.)*

Ins.12 6 0 1 2 3 4 5 6 *Feet.*

Fig. 4. *Plan.*



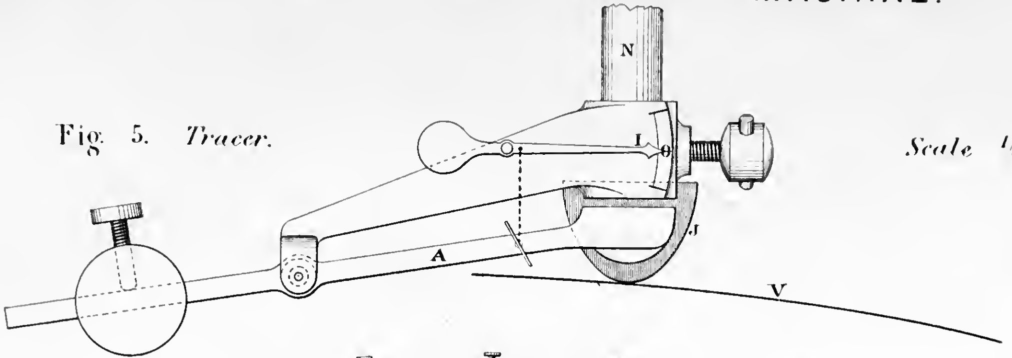
Scale 1/24th.

Ins. 12 6 0 1 2 3 4 5 6 Feet.

SHIP MODEL MACHINE.

Fig. 5. Tracer.

Scale 1/3 rd



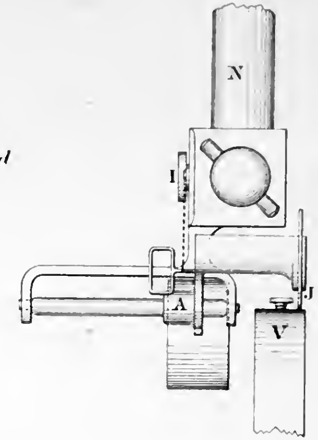


Fig. 6.

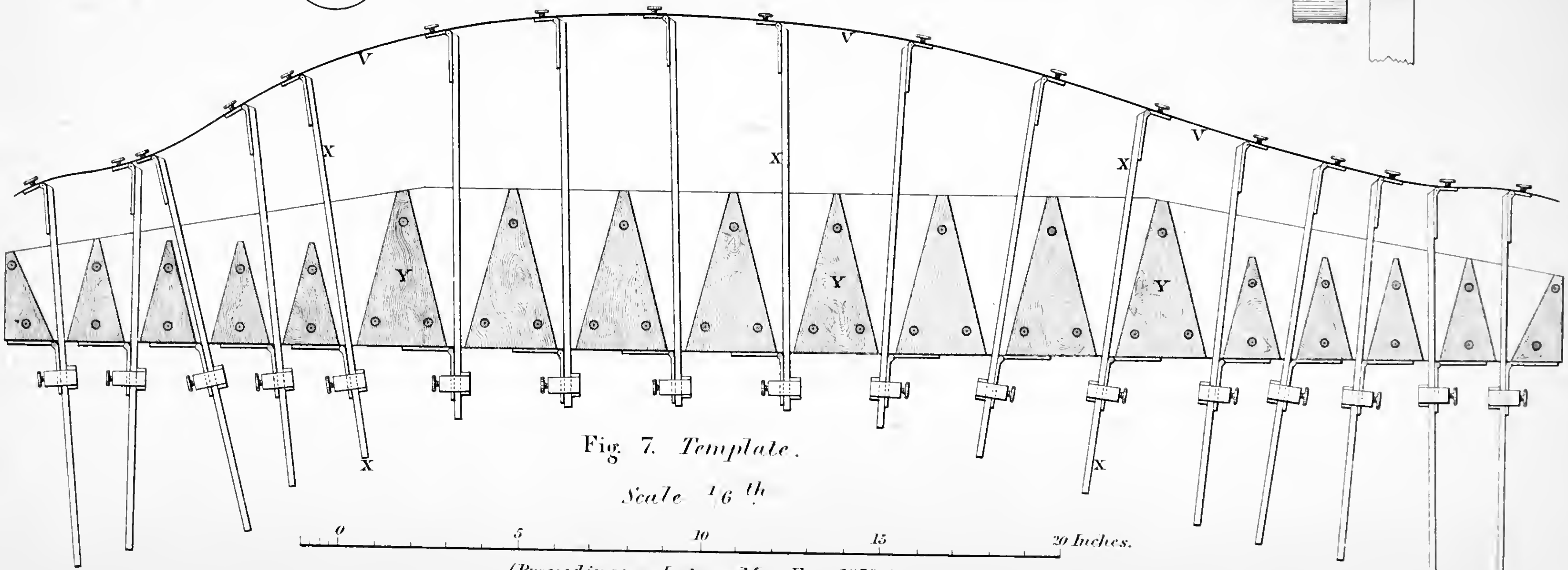


Fig. 7. Template.

Scale 1/6 th.

(Proceedings Inst. M. E. 1873.)

Fig. 8.

Plate 70.

TORQUAY WATERWORKS SCRAPER.

Fig. 1. *Section along course of Main from Tottiford to Torquay.*

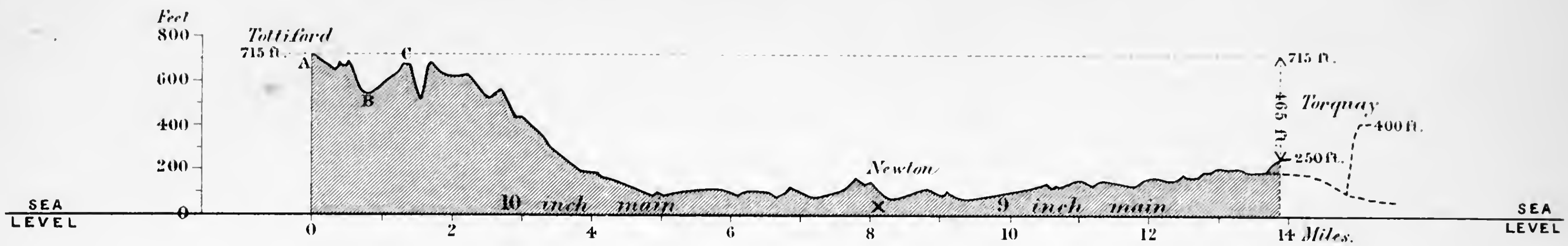


Fig. 2. *Plan.*

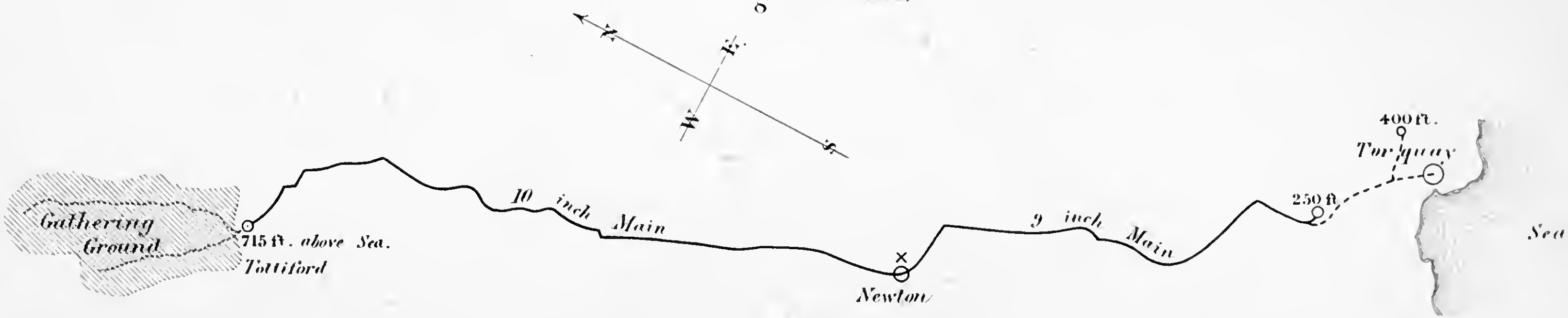


Plate 71.

TORQUAY WATERWORKS SCRAPER.

Fig. 3. *First Scraper.*

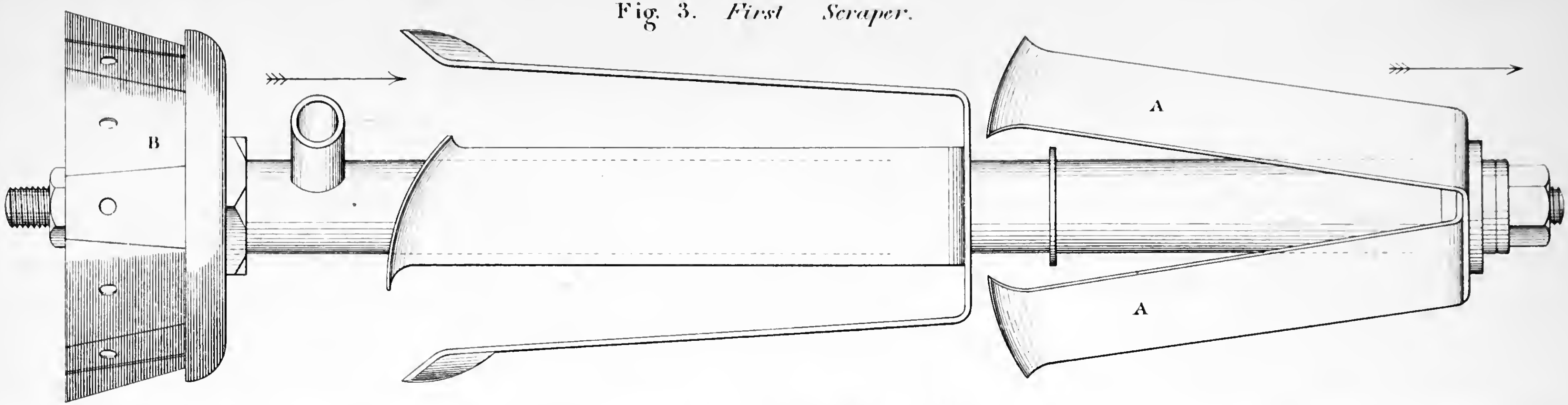
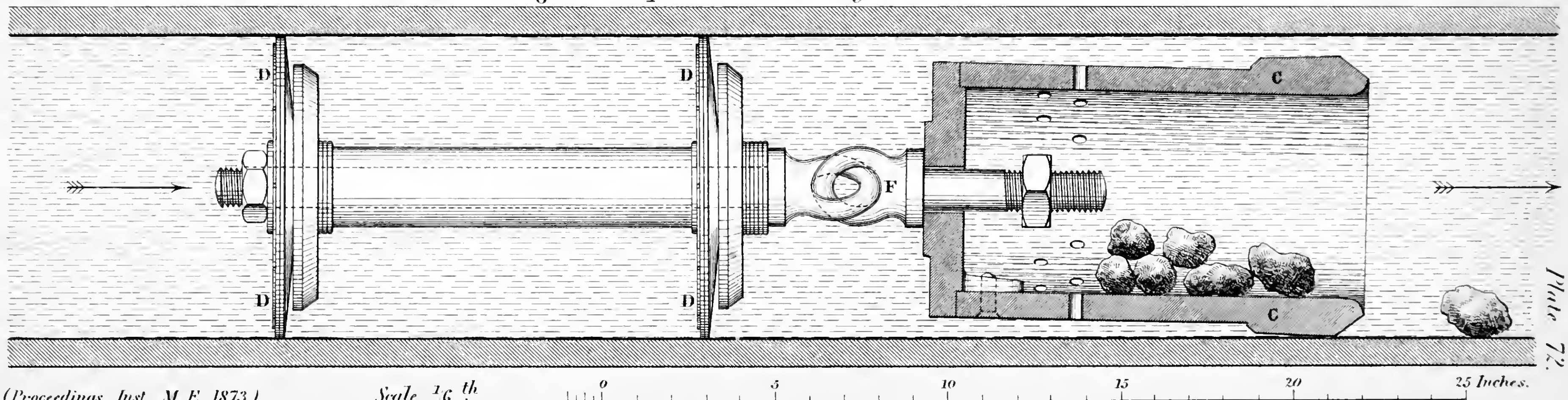


Fig. 4. *Cup for removing Stones.*



Scale 1/6th.

TORQUAY WATERWORKS SCRAPER.

Nine inch Scraper.

Fig. 5. *Elevation.*

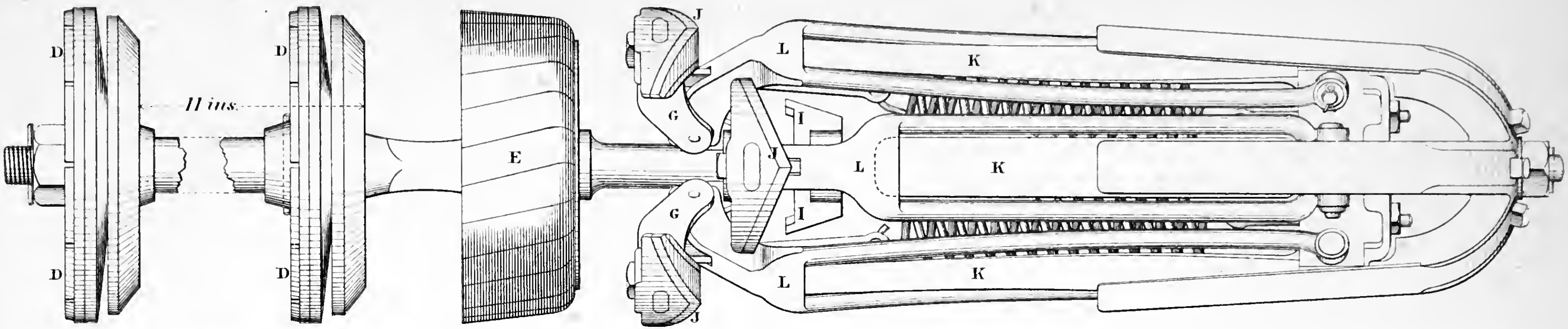
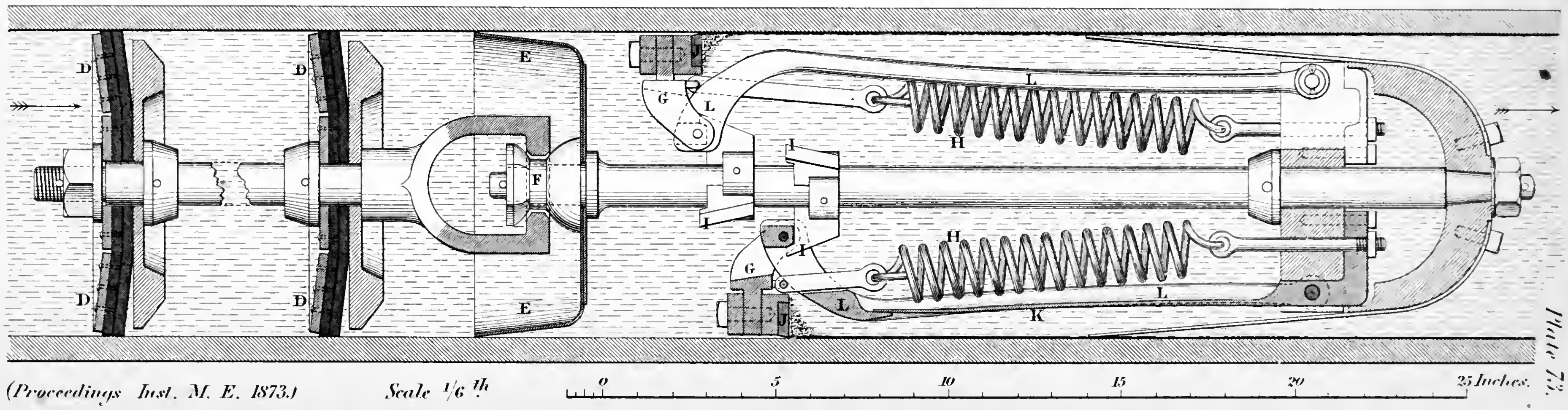


Fig. 6. *Longitudinal Section.*



(Proceedings Inst. M. E. 1873.) Scale 1/6 th

Plate 73.

TORQUAY WATERWORKS SCRAPER.

Nine inch Scraper.

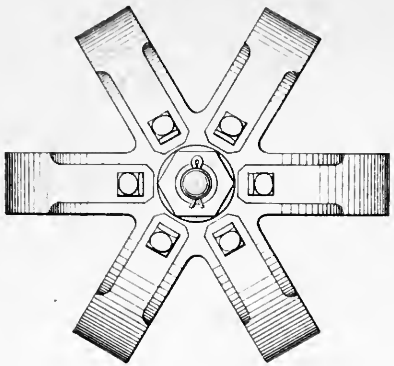


Fig. 7.

Eight inch Scraper.

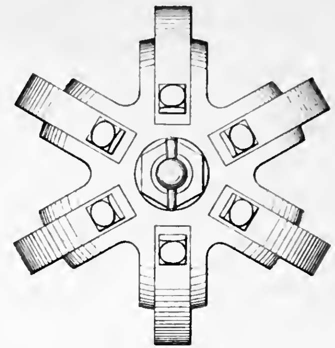


Fig. 9.

Front Elevations, showing front guide arms.

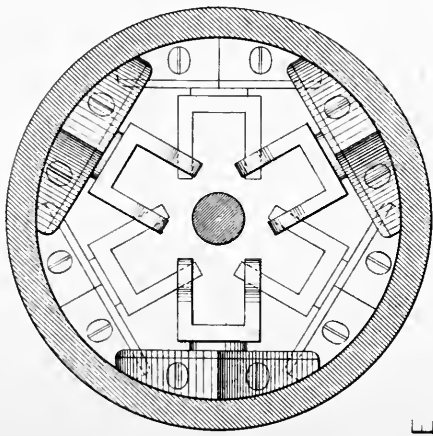


Fig. 8.

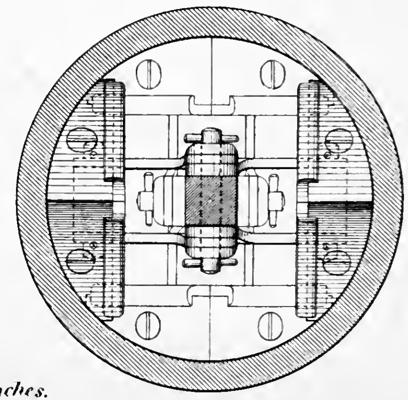


Fig. 10.

Transverse Sections, in front of scraping knives.

Scale 1/6th

0 5 10 *Inches.*

(Proceedings Inst. M. E. 1873.)

Plate 74.

TORQUAY WATERWORKS SCRAPER.

Eight inch Scraper.

Fig. 11. *Elevation.*

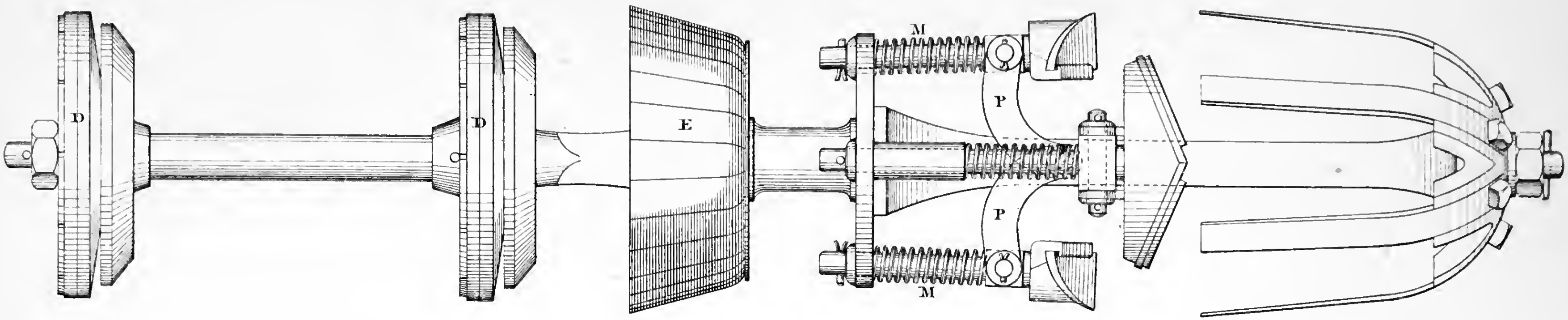


Fig. 12. *Longitudinal Section.*

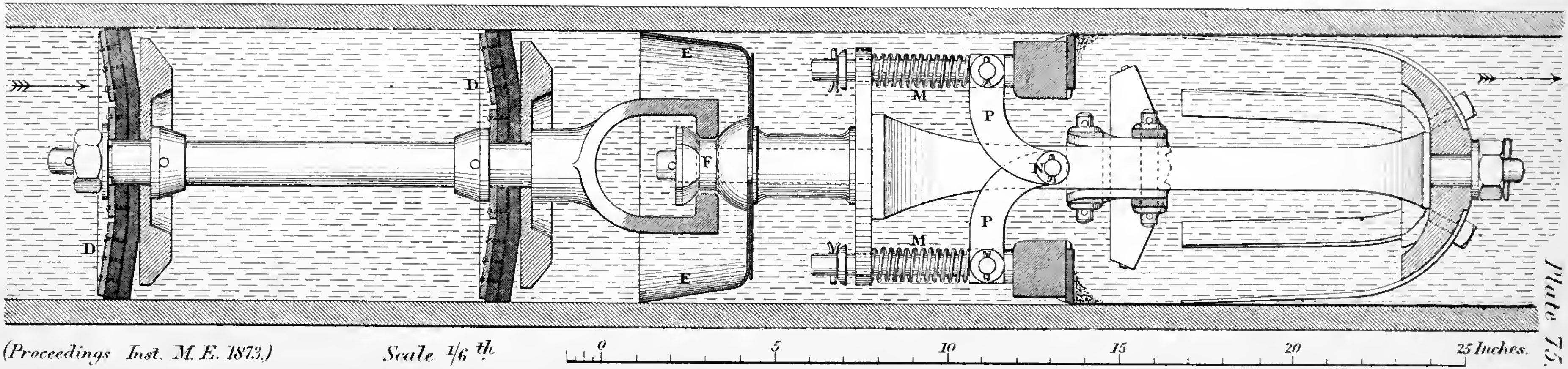


Plate 75.

(*Proceedings Inst. M. E. 1873.*)

Scale 1/6th

ON THE APPLICATION OF PORTABLE ENGINES FOR MINING PURPOSES.

By Mr. JOHN RICHARDSON, of Lincoln.

The Portable class of engine with multitubular boiler and self-contained machinery has been applied in recent years for the purposes of winding and pumping at mines in Cornwall and other districts, in place of the old plan of large stationary engines and boilers; and the results of actual working have shown that the portable engines possess several advantages in economy of working and construction, and convenience of application and maintenance. This application of the portable class of engine has been successfully carried out by Messrs. Robey at several different places during the last fourteen years, and the arrangements employed for the purpose are illustrated in the accompanying drawings, Plates 61 to 64.

In Plate 60 are shown comparative views of one of the old make of winding engines that has recently been removed, and of the new semiportable class of engine that has been adopted in its place: showing the winding gear and the foundations and buildings required in each case.

The Old engine, Figs. 1 and 2, which is a representative of the large number in general use in many mining districts, is a vertical beam engine with single cylinder about 28 inches diameter and 5 feet stroke, driving by gearing a large winding drum at half the speed of the engine. Steam is supplied by one or more Cornish boilers, or more frequently plain cylindrical egg-ended boilers, working at a low pressure of about 20 lbs., and set in brickwork with a high chimney.

The New engine, shown in Figs. 3 and 4 to the same scale, is of the same total power as regards the work performed; and it will be seen how great is the saving in the space occupied and in the cost of erection, as compared with the old engine. The new engine being entirely self-contained and combined with its boiler requires scarcely any foundations or erection for setting it to work; but in the case of the old engine a large outlay of cost and time is required for the foundations and erection of the engine and boilers. The new engine has the advantage that, on account of the firehole and the engine levers being situated in close proximity, it admits of being conveniently worked by only one man for both firing and driving, instead of requiring a separate fireman as in the case of the old engine. The new engine works at a much higher speed of revolution than the winding drum, and is connected to it by gearing of 6 or 8 to 1, instead of the engine having only double the speed of the drum, or being coupled direct to it at the same speed; this gives an important practical advantage in the power of control over the working, as the smaller engine can be stopped in the same fraction of a revolution as the larger one, so that the risk of overwinding the drum is reduced in the same proportion as the ratio of the gearing is increased. Having two cylinders with right-angled cranks, the new engine has the advantage over the old single-cylinder engines of being able to start and stop in any position, as in the case of the modern horizontal double-cylinder winding engines that work direct on to the shaft of the drum; and the handling of the engine in working is particularly simple and easily acquired.

In respect of economy of working, the new engine compares favourably with the old form; and although it is of the non-condensing class, it is found to have an important advantage in economy of fuel over the old condensing engines of large size. This arises from the circumstance that the new engine has jacketed cylinders in which high-pressure steam is largely expanded, instead of the large unjacketed cylinder of the old engine, in which low-pressure steam is worked with scarcely any expansion. Also the multitubular boiler of the new engine yields a higher rate of

evaporative duty than that obtained from the boilers generally employed with winding engines, which is usually not more than about 6 lbs. of water per lb. of coal, whilst the evaporative duty of the multitubular boiler is fully $7\frac{1}{2}$ lbs., giving an economy of 20 per cent. in fuel. A special source of economy of fuel in the smaller engine in the case of metalliferous mines, though not at coal pits, is found in the circumstance that the work of a winding engine is not continuous but intermittent, the engine often working for one minute and then standing for five minutes or longer; so that on the average of the day's work the engine is several times longer standing than working. During all the time the engines are standing, their cylinders are cooling, and however well these may in both cases be protected by non-conducting covering, some heat must be lost, and the loss will be greater in the larger cylinder in proportion to its greater extent of surface. The smaller cylinders being kept hot by steam-jackets, condensation of the working steam is prevented, the only loss being the small quantity of steam condensed in the jackets. Moreover the multitubular boiler works with an artificial quick draught produced by the blast of the exhaust steam in the chimney, and is thus able to use a much inferior description of fuel compared with boilers having only an ordinary chimney draught. In most cases the new engine works with slack or small coal; and in some instances that have come under the notice of the writer, the fuel has been the refuse ashes from stationary boilers, mixed with coal to the extent of as much as about two thirds ashes. Another advantage obtained from the artificial draught produced by the blast, as compared with an ordinary chimney draught, is that the draught ceases the moment that the engine stops, and the fire is then as it were automatically damped down.

Two different kinds of these new engines are in use for mining purposes. The one shown in Figs. 5 and 6, Plate 61, is used principally for sinking trial pits; and as its employment in any situation is usually only temporary, the engine is made not only portable but also self-propelling like a road locomotive. It consists of a locomotive boiler, upon which is mounted a double-cylinder

engine; the crank shaft has a pinion A at each end, which drives through an intermediate wheel E a winding drum D on each side of the boiler. These winding drums run loose on the main axle, on which are also the travelling or driving wheels. Each pinion is thrown in or out of gear by a clutch and lever C, and each drum is fitted with a break worked by a screw and handwheel B; the engine is furnished with the ordinary link-motion reversing gear F, and H is the stop-valve lever. On each travelling or driving wheel is fixed a wrought-iron plate containing two slots J J, in which are fixed a couple of square studs that can be slided up into snugs cast on the inside of the winding drum; the travelling wheels will then be driven at the same speed as the winding drums, and the engine thus becomes self-propelling. On arriving at its destination, nothing further is required than to run the engine into position, chock the wheels, and disconnect them from the drums, which are then immediately ready for winding. When the sinking or winding is finished, the engine can with the same ease steam away to a new situation; or it may be employed as an ordinary portable engine.

The other kind of engine, shown in Figs. 7 and 8, Plate 62, is of semiportable description, and may be employed not only for sinking purposes, but also with great advantage as a permanent winding and pumping engine in the regular working of a mine. A double winding drum D is mounted loose on a shaft at one side of the boiler, one end of the shaft being carried in a bearing fixed on the boiler, and the other end in a wall box built into the engine-house wall, or in a bearing fixed upon a timber frame. On the outer end of the drum shaft is keyed an ordinary pumping crank G with throws of different lengths. The drum shaft is driven by a spur wheel K keyed upon it, gearing with a pinion A on the crank shaft of the engine, and the drum is thrown out of gear with the shaft by a sliding clutch C whenever it is required to pump only; the friction break B attached at one side of the drum is applied by means of a treadle. The engine is fitted with link-motion reversing gear F, for winding alternately upon the two sides of the drum. These engines are employed in raising loads of from 1 to 4 tons from various depths and at speeds of from 250 to 600 feet per

minute. The drums are 6 feet diameter and hold 2000 feet or 330 fathoms of wire rope 1 inch diameter; in order to render the ropes more flexible for working on drums of this small size, they are made with a greater number of strands than ropes intended for larger drums.

In Fig. 9, Plate 63, is shown one of these semiportable engines fitted with two sets of drums and clutches, specially arranged for working with a tail rope at the bottom of a shaft; and this example illustrates in a marked manner the advantage of this class of engine in regard to economy of space, the whole engine and boiler being here lodged in a recess cut at one side of the tramroad near the bottom of the shaft. One end of the drum shaft is carried as before by the boiler barrel, and the other in a wall box on the opposite side of the road; and the drums themselves are fixed sufficiently high to permit the passage of men and horses beneath them. This engine is at work at the Ravenhead Colliery, St. Helen's, at a depth of 310 yards from the surface, hauling along a level of 1100 yards length by means of a tail rope.

When it is required to erect an engine of large power in a situation where the means of transit are not good, and where also there does not exist the requisite tackle for getting heavy weights into position without much expense and trouble, as in some of the colonies and other newly developed countries, the class of engine shown in Fig. 10, Plate 64, is employed, consisting of a pair of complete engines and boilers combined, each the exact counterpart of the other. On each boiler barrel is fixed a bracket carrying the bearings for the drum shaft, which thus requires no other support; a single winding drum or a pair of drums are either keyed fast on the shaft, or left loose upon it and thrown in and out of gear by clutches, as circumstances may require. In the engraving both drums are shown loose upon the shaft, and the clutches are so arranged that either or both drums may be driven by the engines, or by either engine alone, if the connecting-rods of the other be temporarily uncoupled from the crank shaft for repairs. The flanges of each drum form the breaks, being covered with elm blocks about 4 inches thick, with a wrought-iron

break-strap half round. The whole of the levers for managing the pair of engines are brought together in a convenient position in the centre of the platform, H being the stop-valve lever, F the reversing handle, C C the clutch levers, and B B the break treadles.

The following results have been obtained from the application of a number of these new engines in different mining districts of the country, as regards economy in fuel, economy in cost of attendance, and economy in first cost of construction and fixing: the comparison in each case being made with the previous engines of ordinary construction, which had been employed for doing the same work.

In regard to economy of fuel, the saving with the new engines has been found to be from 15 per cent. of the previous consumption up to as much as 40 per cent. In one or two cases where a larger saving has been reported, the old engines and boilers that had been replaced were not only of bad construction originally, but were very much out of repair. From the accompanying indicator diagrams shown in Fig. 11, Plate 65, which have recently been taken from two of the semiportable winding engines now working in Cornwall, it is found that the loss of power from friction is about 15 to 17 per cent.; and in an ordinary Cornish single-acting beam engine doing the same work the loss from friction is found to be nearly 50 per cent., as ascertained from the indicator diagrams shown in Fig. 12.

The saving in cost of attendance with the new engines is also found to be from 15 to 40 per cent. of the previous cost with the old engines and boilers.

The saving in first cost, taking into account the whole of the buildings, foundations, and chimneys required for the ordinary fixed engines and boilers, has ranged from 10 and 25 per cent. up to as much as 66 per cent. of the cost of the old engines, boilers, and buildings. This great disproportion is explained by the great difference in the cost of building materials and labour in different localities, the advantage of the new engines being of course the greatest where these expenses have been the heaviest.

At Boscaswell Downs Tin Mine, St. Just, near Penzance, one of these semiportable engines of 20 horse power has now been in use for more than a year, winding from a depth of 210 fathoms in a shaft sunk on the course of the lode at an inclination of 1 in 6 from the vertical. The engine has a pair of $10\frac{1}{4}$ inch cylinders with 14 inches stroke, and works at about 125 revolutions per minute, with 60 lbs. steam; it has two winding drums, and is worked sometimes with and sometimes without the second rope; the diameter of the drums is 6 feet, and of the wire rope 1 inch. The gross load raised at each time of winding is about 3 tons, the skip containing about $1\frac{1}{2}$ tons of mineral; the speed of winding varies according to circumstances, and the loaded skip is brought up from the bottom of the shaft in 2 minutes when all is clear; and in regular working about ten journeys are made per hour from the bottom of the shaft. The fuel that the engine is burning is two thirds of it obtained from the heap of ashes left by the previous Cornish engine, and the saving in cost of fuel is 25 per cent. as compared with that engine, which however was an inferior description of engine; in comparison with an ordinary Cornish winding engine the saving in cost of fuel is about 15 per cent. The saving in cost of attendance is 25 per cent. and the entire first cost of the present engine has been only one third of that of the old engine it has replaced. The new engine continues in as good condition now as when started a year ago; and a second similar winding engine has this year been added at the same mine.

At Shildon Colliery in Durham a semiportable winding engine of 16 horse power has now been in constant use for four years, having two winding drums, one of which draws the coals up the shaft from a depth of 50 fathoms, raising each time a gross load of $1\frac{1}{4}$ ton. The second drum hauls loads of $8\frac{1}{2}$ tons up an incline of 1 in 18 to 1 in 12 and 100 yards long at the bottom of the shaft. Steel ropes of $\frac{1}{2}$ inch diameter are used, the drums being $3\frac{1}{2}$ feet diameter. The fuel burnt is entirely coal from the pit, and the saving is found to be from 30 to 40 per cent. as compared with an ordinary condensing engine with egg-ended boilers; the saving in cost of attendance is about 40 per cent. This engine was originally employed for sinking

the two shafts of 14 and 16 feet diameter; and continues in pretty good repair after four years' constant work.

At the Talysarn Slate Quarries, near Carnarvon, a semiportable winding engine of 12 horse power has been at work for about four years, during which time it has continued in good order, and has done its work with an expenditure of fuel less than one half of that which would be required with the ordinary fixed winding engine working with Cornish boilers. It is employed in raising the slate rubbish up an incline of about 40° from the horizontal and about 160 yards length, the engine being placed on the top of a large mound of slate rubbish, and employed in building it still higher. The drums on this engine are only 2 ft. 7 ins. diameter, yet a steel wire rope $\frac{5}{8}$ inch diameter, which was put on four years ago, continues apparently as good as ever, although about 300,000 tons of material have been raised by it. The increased durability of the rope in this instance is due to the fact of the steel wire having been tempered comparatively soft, which is a point of much importance in connection with these portable engines, as the diameter of the drums is necessarily limited; other steel ropes at the same quarries made of hard-tempered wires were found to fail continually in the strands. From numerous enquiries made respecting the ordinary duration of the wire ropes employed with the portable mining engines it is found that they last from one to two years, showing that the fact of using drums of small diameter does not tell so much against the ropes as might have been imagined, provided the ropes are made of suitable size and material; the ropes are generally thrown out of use or put to lighter work after one or two years' use, though in some cases they last much longer.

At the New Beldon Lead Mines, near Blanchland, Northumberland, a semiportable engine of 20 horse power has been employed for nearly two years in sinking and working a shaft, and it is stated by the mine agent to be exceedingly well adapted for the purpose. In addition to raising the mineral, it has worked continuously an $8\frac{1}{4}$ inch pump with 6 feet stroke, raising 89,000 gallons per 24 hours from a depth of 24 fathoms, with a consumption of 16 to 17 cwts. of very inferior coal.

From the experience already gained in the working of these engines, and taking into consideration all the circumstances of their economy and other advantages, there seems reason to expect a further extension of their application to mining purposes with beneficial results.

Mr. Richardson mentioned that the indicator diagrams exhibited from the portable engines were taken from the two winding engines working at Boscaswell Downs mine, and the other diagrams were from an ordinary Cornish winding engine still in use at the same mine.

The Chairman enquired what was the real consumption of fuel in these portable engines in proportion to the actual work done, say with Welsh coal.

Mr. Richardson replied that with good Welsh coal the consumption in the portable engines was about 3 lbs. of coal per indicated horse power per hour, the power being that measured in the cylinder by means of indicator diagrams; with inferior coal the consumption rose to 5 lbs. Doubts had sometimes been expressed, especially in Cornwall, as to the greater evaporative efficiency of the multitubular boilers of locomotive and portable engines compared with the Cornish boiler; but from a number of experiments that he had made upon this point he had found the multitubular boilers really did evaporate more water per pound of coal than the Cornish boilers, when the latter had been a number of years at work. From his own experiments he had come to the conclusion that Cornish boilers could not be depended upon to evaporate more than 5 or 6 lbs. of water per lb. of rough slack coal such as was ordinarily used for steam boilers. In the paper he had put down $7\frac{1}{2}$ lbs. of water as the evaporative

duty of the portable engine boiler; but from one of these boilers he had himself obtained an evaporation of as much as 11 lbs. of water per lb. of coal, and in the trials of the Royal Agricultural Society even $11\frac{1}{2}$ lbs. evaporation was sometimes got from very good boilers of this class. The difference therefore in evaporative duty of the two classes of boilers would alone account for a great part of the saving effected by the portable engines as compared with the ordinary stationary engines and Cornish boilers.

Mr. Froude enquired whether the evaporative duty was measured by the water consumed in the boiler, or by the steam passing through the cylinder as ascertained from the indicator diagram.

Mr. Richardson replied that he had measured the water supplied into the boiler during a whole day by a meter, checking the consumption by calculation from the expenditure of steam shown by indicator diagrams taken occasionally during the time.

Mr. Jeremiah Head enquired how many times per hour the operation of firing was performed when the portable engines were in regular work; and how often for obtaining the highest results in evaporative duty.

Mr. Richardson said that in the case of winding engines the rate of firing depended of course very much upon the weight of material that was being raised at the time. In the regular working of the winding engines at Boscaswell Downs mine, the firing was ordinarily done every five or ten minutes, and sometimes there was as much as twenty minutes' interval without charging any coals. For the evaporative duty mentioned in the paper of 8 lbs. of water per lb. of coal, it would be quite sufficient to fire once every ten minutes; but for evaporating as much as 11 lbs. in the agricultural trials it was necessary to charge the coal in very small quantities every two minutes.

Mr. W. Husband asked whether in these statements of evaporative duty the water was evaporated under the ordinary boiler pressure, or simply at atmospheric pressure.

Mr. Richardson replied that in the portable engines described in the paper the water was evaporated under the regular working pressure of 60 lbs. per square inch above the atmosphere.

Mr. T. LEAN enquired whether any data could be furnished as to the total actual quantity of coal consumed and of material raised during a given period by the portable winding engines at Boscaswell Downs mine.

Mr. RICHARDSON said he had not been able to obtain that information, as at scarcely any of the Cornish mines was the trouble taken to keep an account of the weight of material raised in relation to the consumption of coal.

Mr. W. HUSBAND observed that the results which had been stated of the evaporative duty of the portable engines had been obtained with good Welsh coal; and he enquired what was found to be the difference in evaporative value between that coal and the ordinary mining coal used in Cornwall, which was what he presumed the winding engines at Boscaswell Downs mine were working upon. With the best Welsh coals a duty of $10\frac{1}{2}$ or 11 lbs. of water evaporated from 212° Fahr. under 15 lbs. steam pressure could be obtained with a Cornish boiler, and taking that coal to be about 30 per cent. superior to the ordinary mining coal used in Cornwall, the evaporative duty of the latter would be about $7\frac{1}{2}$ to 8 lbs. of water per lb. of coal. Similarly the consumption of 3 lbs. of good Welsh coal per indicated horse power per hour in the portable engines would be equivalent to 4 lbs. of the ordinary coal.

Mr. RICHARDSON thought it would scarcely be fair to the portable engines to take the performance of those at Boscaswell Downs mine as a test of what could be done. The engines at that mine were simply using one third ordinary mining coal and two thirds ashes from other engines, and had worked sometimes for a whole day entirely upon the latter. The saving of coal was accordingly considerably over 15 per cent., in comparison with the best Cornish engines that he knew of; and as compared with the old Cornish winding engine, previously employed there, which had been a very bad one, the saving was more than 60 per cent. He had scarcely found so much difference as 30 per cent. in evaporative duty between good Welsh coal and the ordinary Cornish mining coal. He should be glad to hear some further particulars about the high evaporative duty of 11 lbs. of water in a Cornish boiler with Welsh coal.

Mr. W. Husband said he had himself obtained that result by experiment; he did not mean to say that so good a duty was generally being obtained, but that it could be obtained.

Mr. Richardson said, although he had on previous occasions been given to understand that 11 lbs. of water could be evaporated in Cornish boilers per lb. of coal, he had never succeeded in obtaining from his own experiments a confirmation of that result. From the experiments of Mr. Robert Longridge communicated at a former meeting of the Institution (see Proceedings Inst. M. E. 1859 page 161) it appeared that the evaporative duty of different cylindrical boilers with two or more internal flues ranged from 6·86 up to only 8·61 lbs. of water evaporated from 212° Fahr., under steam pressures of from 40 to 55 lbs. above the atmosphere, with good Lancashire steam coal and slack.

Mr. W. Husband mentioned that the experiments he had referred to, in which he had obtained from Cornish boilers with the best Welsh coal a duty of more than 10 lbs. of water evaporated from 212° under 15 lbs. steam pressure, had been made in connection with the Cornish pumping engines erected in Holland by Messrs. Harvey for the drainage of Haerlem Lake; those engines were required to perform a certain amount of work with a given quantity of best Welsh coal, and as that coal could not be got in Holland for the regular supply of the engines, experiments were made to ascertain the relative value of the coal actually used, in comparison with the best Welsh coal; the coal used for the engines was the Ruhrort coal, from collieries in Germany. The result of those experiments as regarded the Welsh coal was confirmed by Sir H. De la Beche's experiments made for the Admiralty about twenty-five years ago in reference to the fuel suitable for use in the British navy, in which it was found that with a Cornish boiler the evaporative duty obtained from Powell's Duffryn (Welsh) coal was 10·45 lbs. of water evaporated from 212° Fahr., with Ebbw Vale coal 10·20 lbs., and with Warlich's fuel 10·36 lbs. He thought the results of these different experiments were sufficiently conclusive as to the evaporative duty of the Cornish boiler in comparison with other descriptions of boilers.

There were one or two other points with regard to the ordinary Cornish winding engines, in reference to which he could not agree with the views advanced in the paper. For instance, a separate fireman was not required, the firing being done by the same man who drove the engine and attended to it generally; therefore he did not see how the expense of working the ordinary winding engine could be more than in the portable engine. As to the comparison between the high pressure of steam that was used in the portable engine and the low pressure employed in the ordinary winding engines, it was true that there had been great carelessness in Cornwall for many years past in reference both to winding and to pumping engines; but it should not be forgotten that some of the earliest high-pressure engines had been used in that county by Trevithick, working at 70 lbs. pressure per square inch, and non-condensing. The steam-jacket too was first used in Cornwall, and was very generally employed at the present time, all the best winding engines being steam-jacketed; while other steps were also taken to ensure the utmost practicable perfection of working. With regard to the saving of coal in the portable engine by the stoppage of the blast when not working, the ordinary damper would of course have the same effect in other engines. For sinking trial shafts and for many other purposes the portable engine would do very well; but when a mine was more opened out and all operations were being fully and regularly carried on, the best possible permanent engine was wanted, and he considered a fixed engine was then preferable for continuous working for a lengthened period, as the best engine could not be a high-pressure non-condensing engine. At the present time he believed the best Cornish winding engines, which were high-pressure condensing engines, were not consuming more than $4\frac{1}{4}$ lbs. of the ordinary mining coal per indicated horse power per hour; and there were many engines for which that would be an excessive consumption. The best engine he considered would be a combined one, having high-pressure and low-pressure cylinders coupled at right angles, such as were used for marine purposes; vessels had been built and engined on that plan by his own firm, in which the consumption

had been brought down to $1\frac{3}{4}$ lbs. of best Welsh coal per indicated horse power per hour, and by that arrangement therefore he believed a saving of 50 per cent. could be effected in the consumption of coal as compared with the portable engines now described. A combined horizontal engine with the two cylinders in the same line and connected to the same crank had lately been put up by his firm for driving the pneumatic stamps at Carn Galver tin mine, between St. Just and St. Ives, in which the consumption was only 3 lbs. of the ordinary mining coal per indicated horse power per hour; the cylinders were 9 and 17 inches diameter and 15 inches stroke, making 150 revolutions per minute, with a boiler pressure of 70 lbs. per square inch; but in that case the cylinders were not jacketed. This he thought was the direction in which economy must be looked for; it was necessary for the sake of economy that the engine should be a condensing one, and he was satisfied that combined high-pressure condensing engines could be erected for winding purposes in Cornwall, which with ordinary Cornish boilers should use only 2 lbs. of the best Welsh coal per indicated horse power per hour.

Mr. Jeremiah Head called attention to the statement that the portable winding engines described in the paper were fed with fuel, two thirds of which was composed of ashes from the Cornish boilers, and one third only was coal. It appeared to him that the firegrates of the boilers from which those ashes came must be very badly managed, or such a quantity of combustible matter would not be permitted to fall through. If an iron ladle were placed upon a fire till it became red-hot and then a little coal dust were introduced, the whole of the gas would be found to pass off in a few minutes, but the solid coke left behind would require above two hours for complete combustion; this showed that, if coal was to be used economically in any grate whatever, a long time must be allowed for the utilisation of the solid portion. It was the habit of most stokers to do a great deal of poking or stirring, thereby causing a quantity of coke to fall through into the ashpit in an unconsumed state. He had made a series of experiments with the view of ascertaining the proportion of ashes made to coal consumed, and

had found that with common long egg-ended boilers as ordinarily worked the so-called ashes amounted to $11\frac{1}{2}$ per cent. of the total quantity of coal used, where the really incombustible portion was only $1\frac{1}{2}$ per cent. This showed that 10 per cent. of the coal actually passed through into the ashpit unconsumed. In the boilers of a marine engine he had found $14\frac{1}{2}$ per cent. to pass through unconsumed, and in puddling furnaces from 20 up to even 33 per cent. The boilers of Cornish engines must be very badly stoked to yield ashes to such an extent as to supply two thirds of the fuel to the portable engines described in the paper; and if these portable engines were only stoked as badly, it would be possible to take the ashes from them and burn them over again under the Cornish boilers with advantageous results. The first condition necessary for economy was to burn thoroughly the coal put upon the grates; and this was simply a question of proper construction of grate and proper care in stoking, and quite irrespective of the class of engine employed. He agreed in the opinion that the portable engines were of much use for temporary works, where they were likely to be often shifted; but he did not think a construction such as that shown in the drawings was the best for permanent engines. For regular work an engine should not be liable to shake, as was more or less the case with all portable engines where the engine and flywheel were mounted on the top of the boiler. For steady working he considered not only the second-motion shaft and drums but also the driving shaft and flywheel should be on the ground level, instead of being raised up so high. It seemed to him that, in this application to mining purposes of a type of engine developed in a totally different field of experience, the special conditions which a permanent mining engine ought to fulfil had not been recognised with sufficient clearness.

Mr. F. W. Michell remarked, with respect to the evaporative duty of Cornish boilers, that in experiments which he had made himself he had been able to obtain an evaporative duty of 10 lbs. of water per lb. of coal with Welsh coal, not of the best quality but tolerably good; in that case the water was evaporated from the temperature of spring water. He did not think the evaporative duty

of the mining coal supplied to Cornwall was generally so good, inasmuch as there was fully the difference that had been mentioned of 30 per cent. in the quality as compared with good Welsh coal. Latterly indeed he did not consider that anything fit to be called coal had been sent into Cornwall at all; the stuff supplied was simply from the refuse heaps of the collieries, which could not be disposed of elsewhere. As to the use of ashes for fuel, he had known a 40 inch Cornish pumping engine work entirely upon its own refuse ashes for 48 hours, pumping a mine 200 fathoms deep; probably there was something wrong with the firegrates, or the stoking was not attended to with sufficient care, so that the coal was not consumed so completely as it ought to have been; and he suggested that the same might be the case at Boscaswell Downs mine with the boilers which had supplied the ashes for the portable engines. So far as winding engines were concerned, he did not think a high-pressure non-condensing engine could be the best and cheapest form; it appeared to him that an engine with long stroke, using 50 or 60 lbs. steam cut off at one fifth or one sixth of the stroke and expanded down to a good vacuum, and having the cylinder steam-jacketed and all the pipes well clothed, must work more economically than the high-pressure non-condensing engines described in the paper. The friction of the portable engines had been stated at about 15 per cent. of the total power, and he believed the friction of good Cornish winding engines was not more than that, if so much. Loss of power in friction meant simply that the engine was expending a certain proportion of its power in wearing itself out; and seeing that many Cornish winding engines had been running for thirty years and upwards, he did not consider the friction in them could be anything very serious, otherwise the cylinders must have been worn out long before that length of working could have been attained.

Mr. G. D. Hughes enquired whether in the portable engines there was any arrangement for heating the feed water. He had been somewhat taken by surprise with regard to the great economy stated to be obtained with these engines as compared with the Cornish engines; and in reference to their consumption of one third coal and

two thirds ashes, and the further statement that with good Welsh coal their consumption was about 3 lbs. per indicated horse power per hour, he enquired whether it was meant that the coal alone was taken into account and that the ashes were not reckoned, making the actual consumption 3 lbs. of coal and 6 lbs. of ashes; or whether the consumption was 3 lbs. of the mixed material, consisting of 1 lb. of coal and 2 lbs. of ashes. With regard to saving in attendance, he could not see that any more attention was required by the Cornish engine than by the portable engines now described. In reference to the use of steel wire ropes of $\frac{5}{8}$ inch diameter with the winding engines described in the paper, he should be glad to know what weight of load was lifted with ropes of that size.

Mr. T. Lean observed that, as the ordinary mode of computing the duty of engines in Cornwall was in millions of foot-lbs. of work done with the consumption of 1 cwt. (112 lbs.) of coal, it would be convenient for comparison if the duty of the portable engines at Boscaswell Downs were similarly stated; and he should be glad to hear some further particulars about the actual consumption of fuel in the portable engines, and whether they were really burning no more than one third coal. At the present time economy of fuel was indeed a most important question in Cornwall, and he knew that district was now considered to be far behind others in the matter of drawing the stuff to surface; nor could it be denied that the duty performed by the engines had been very seriously retrograding in recent years. It was therefore highly desirable that the subject should be thoroughly ventilated; and he was quite sure that any improvements, whereby it could be satisfactorily shown that the stuff could be brought to surface in a cheaper manner than hitherto, would be readily adopted at the mines throughout the county.

Mr. D. Halpin thought it was erroneous to object to the portable engines on the score of low duty, for he believed that in first-class engines the duty would be probably 60 or 70 millions. With regard to the consumption of inferior fuel, he thought much might be learnt from the practice in Belgium, where a very large proportion of the coal burnt in the locomotives was of so low a quality that it would not

be used at all on any railways in this country. The portable engine he considered had shown itself capable of doing quite as good duty as the locomotive, with the same description of fuel.

Mr. C. E. Amos said he had watched the progress of the portable engines from their earliest form, in which they had been very wasteful of fuel, to the present time when they had become a very useful and economical class of engine, although he was not in a position to compare them with the Cornish engines from his own experience. Certainly great care and attention had been bestowed upon the portable engines, and the durability and accessibility of their various parts had been very much increased by the improvements of later years, every effort having been made to render them simple and durable in their construction and easily accessible. He recollected once an instance in which so little attention had been paid to the latter point that the cylinder had been put inside the boiler and riveted over, so that it was impracticable to withdraw the piston at any time for examination or repair; and other equally strange mistakes had been committed. In former years also, in the trials of the portable engines, something more than coal used to be employed for getting a good result in economy of fuel; oil would sometimes be used so liberally for lubricating that it would run down into the ashes, which of course found their way into the grate again. Now however the trials were of a very different character, and for several years past he did not think there had been any attempt to mislead the judges, but he believed the competitions had been honourably carried on, and that the results reported might be taken to be entirely trustworthy as regarded the performance of the engines in the trials.

Mr. Richard Taylor remarked that the performances of many of the engines which were now to be found in daily work drawing the stuff at the mines in Cornwall must not be taken as a measure of the capabilities of a well managed Cornish drawing engine. Many of the present drawing engines had within his own knowledge been moved over and over again from mine to mine, working a good many years at each. It was of course generally the object of the adventurers in starting a new mine to obtain the cheapest

machinery they could, and it was only when prosperity came that they would procure the best that could be got; and he believed the engineering establishments in Cornwall had turned out as perfect examples of winding engines as any that could be made for the purpose. He had himself lately brought into the county one of the portable engines for temporary use as a winding engine, and it had enabled the operations at the mine to be carried on without the loss of a day while fitting new pumping machinery in the shaft and preparing for putting in a good permanent winding engine. In any case of the temporary requirement of engine power at mines, he believed these portable engines might be found most useful, and that they would perform good duty; but he also concurred in the opinion which had been expressed that a good high-pressure engine with a condenser would do better duty than one without.

In reference to the burning of ashes, there was certainly a good deal to be done in the utilisation of ashes, which often contained a considerable proportion of unconsumed fuel; but it must not be supposed that all the ashes from Cornish engines were capable of being used as fuel. A large proportion was earthy matter which originally existed in the coal; and it was easy to ascertain by experiment how much really incombustible ash was contained in any specimen of coal. Unfortunately in the fuel now supplied to the mines of Cornwall there was a very large proportion of stuff that could not be consumed at all, being nothing else than earthy matter. The mines were supposed to be supplied with what was called "through and through" coal from the Welsh collieries, by which term was meant the coal as it came direct from the workings of the mine; but this was by no means the case, as it was well known that the greater proportion of the lump coal was taken out at the collieries, and what was sent to the Cornish mines, though not absolutely the slack alone, still contained a very small proportion of lumps; and during the scarcity of coal in the last year or two, as had been stated, the mines had had to take vast heaps of stuff, which had been lying at the collieries for years past and could never be shipped anywhere

before. It was impossible therefore but that a large quantity of this kind of fuel should find its way into the ashpit unconsumed, although with a reasonably good quality of coal such a result would be unpardonable. In metallurgical furnaces also, for tin and lead smelting, where it was necessary at certain times to stir up the fire vigorously in order to get up the intense heat required, this naturally caused a large amount of coal to fall through the grate unconsumed. At the large Pontgibaud lead smelting works in France, with which he was connected, they had a regular system of dressing the ashes just as the ore was dressed, coal being very expensive there; the whole of the ashes from the smelting furnaces underwent washing, sizing, and jigging, all of which processes were done by mechanical means; the jiggers separated the heavy earthy matter or clinker, which remained on the sieves, while the light pieces of unconsumed coke or "breeze" came to the top and were skimmed off by hand. For the boiler at those works no other fuel was used but these carefully dressed ashes. This was a matter that required a great deal of attention in Cornwall at the present price of coal, and he believed it would be found that much valuable fuel might be extracted from most of the ash heaps now existing; but in stationary engines a good stoker should not let the ashes thrown away contain anything of value for burning.

Mr. E. Easton mentioned that upon the subject of the consumption of fuel in Cornish boilers he had made some practical experiments two years ago in connection with the Brighton Water Works. Trials for Admiralty purposes might be open to the remark that they were made under special circumstances; but in the present instance the trial was made without any special preparation, simply with regard to the consumption of fuel in boilers, some of which had been in use fifteen or sixteen years; and the point to be decided was whether it would be better to use Newcastle coal or Nixon's Navigation Welsh coal. Some of the boilers were of the ordinary Cornish type, with a single internal flue; and two were double-flued boilers made by his own firm, which had been in use four or five years; there were no cross tubes in any of the flues. The boilers were very well set, with a

large chimney, and were in good working order, and they were not forced in the firing. The result of three days' trial with each description of coal, measuring by meter the water supplied into the boilers, was that more than 10 lbs. of water per lb. of coal was evaporated from the hot-well temperature of about 120° or 130° Fahr. under the steam pressure of about 40 lbs. per square inch above the atmosphere; and taking price into account, the Newcastle coal was found to be the cheaper of the two for the purpose. The boilers had about 1400 square feet of evaporating surface and $1\frac{1}{2}$ square foot of firegrate per cubic foot of water evaporated per hour. From his own experience in the manufacture of steam boilers he had been led to prefer the double-flued Cornish boiler for all stationary purposes; or if very pure water could be obtained, he considered the multitubular Cornish boiler, having a set of horizontal tubes at the end of the flues, was the most economical and in the long run the best that could be used. The "through and through" coal, which had been spoken of as being supplied to the mines in Cornwall, might, he thought, judging from the remarks made as to its quality, be taken to mean what had been through and through the sieve pretty often.

Mr. Richard Taylor said it was quite true that a great deal of the coal now sent to the Cornish mines was of such a description that it would run through the bars of the firegrate like sand; and another complimentary designation bestowed upon it by the coal owners was that of "free burning" coal.

Mr. H. Lawrence enquired what was the explanation of the sudden rise that was seen in the middle of the exhaust line in each of the indicator diagrams (Fig. 11, Plate 65) taken from the portable engines; he had noticed a similar defect also in diagrams from other engines. With respect to Cornish boilers, those which he had thus far had an opportunity of seeing in Cornwall seemed to be worked just as badly as was the case in the neighbourhood of Newcastle and Durham. One of the greatest sources of economy in connection with the Cornish boiler he had understood to lie in very slow combustion combined with abundant boiler power, and some of the best examples of properly worked Cornish boilers

were probably those that he had seen at the various water works in London; but in the boilers that he had seen at present in Cornwall he had found the firing was being hurried just as badly as was done in the North. The appellation of Cornish boiler he understood belonged properly to single-flued boilers alone, and double-flued boilers were commonly distinguished as Lancashire boilers. Portable engines were now very much used in Cumberland, Northumberland, and Durham, for temporary purposes, especially for sinking pits, and in some cases for hauling underground; in all large operations it had been found that there was a certain extent to which portable engines could be used with advantage, but afterwards it was necessary to replace them with something more permanent; and when an engine was required for any great length of time in the same position and for heavy work, it was much better and cheaper to erect a good stationary engine in the first instance. The consumption that had been mentioned of 3 lbs. of coal per indicated horse power per hour with the portable engines referred to in the paper did not seem to him very economical; because it was well known that there were at the present time many portable engines which worked much more economically than that.

Mr. Jeremiah Head said he had also understood that the alleged economy of Cornish boilers was due to extremely slow firing, and he had heard that in the best practice it was the habit to fire them only once an hour. He should be glad to know whether this had been the case with the Cornish engines that had formerly given such very high duties.

Mr. W. Husband said that, in order to secure the best result in economy of fuel, the rate of consumption of the coal ought not to exceed one ton in 24 hours with an ordinary 10 ton Cornish boiler, the dimensions of which would be about 30 feet length, 6 feet diameter of shell, 3 ft. 9 ins. diameter of flue, and 6 ft. 6 ins. length of firegrate, giving about 24 square feet area of grate.

The Chairman observed that from those dimensions it appeared the rate of combustion would be rather less than 4 lbs. of coal per square foot of grate per hour.

Mr. Jeremiah Head enquired how often the firing would be done in such a case to keep the consumption down to the amount mentioned.

Mr. W. Husband replied that with good coal and slow combustion the firing would probably be done once in three quarters of an hour. In winding engines, when it was necessary to draw with great rapidity, more coal might be consumed, and the firing might be more frequent; but with pumping engines the firing should be at long intervals and the combustion kept as slow as possible. In Cornwall the highest authority with regard to the duty of engines was the monthly report of Mr. Lean, who, and his father also before him for many years, had had more experience in this matter than any one else. Winding engines were not reported, because they were subject to so many stoppages, which rendered it difficult to ascertain the work actually done, except by weighing the whole of the stuff raised; but stamping engines, which were the same sort of engines as those employed for winding, and were in all points as economical, were reported; and from the best stamping engines at the present time a duty of 60 millions and upwards was obtained. With the best Welsh coal this duty would have amounted to 75 or 80 millions, equivalent to a consumption of less than 3 lbs. per effective horse power per hour.

The Chairman observed that the highest duty recorded in Lean's Reporter for any rotary beam engine in Cornwall during the month of May last was only 42·9 millions.

Mr. T. Lean said that was quite correct; but he knew there was an engine in Cornwall not reported that was working better than any of the rotary engines reported. The pumping engines reported were with very few exceptions the best of the county, the majority of those not reported doing a very low duty.

Mr. Richard Taylor remarked that unfortunately the number of engines reported at the present time was very much smaller than it used to be in former years. Formerly the mine owners were very glad to have it done, and the engineers all did the best they could. He regretted exceedingly that this very important matter had been so much neglected; and he hoped the observations made in the present

discussion would have some effect, and would arouse those who were so greatly interested in the economy of fuel. With regard to the slow combustion that had been spoken of in connection with the Cornish boiler, he recollected the time when some of the engines in the Gwennap mines reported duties of 100 millions per bushel of 94 lbs., equivalent to 120 millions per cwt. of 112 lbs.; and that high result was only gradually arrived at by adding one after another even four or five more boilers, so as to maintain the requisite supply of steam by working the boilers with very slow fires, which were very carefully stoked. In reference to the remark which had been made about applying the appellation of Cornish boiler to a double-flued boiler, he had in his early connection with mining in Cornwall been acquainted with Woolf, who was his father's engineer, and also with Sims, who was then an old man; and he recollected more than forty years years ago seeing engines worked under those engineers by Cornish boilers which had two flues instead of one; ultimately however these were abandoned, and he had had to do with displacing them, because it was considered that the best effect was obtained from boilers having only a single flue.

Mr. T. LEAN showed a diagram which he had prepared (Figs. 13 to 15, Plate 66), representing the duty reported from pumping engines in Cornwall during the last sixty-two years, the particulars of which are given in the table appended (see pages 200 and 201). From these particulars and diagram it would be observed that since 1843 there had been a gradual decline in the amount of duty reported, to the extent of nearly 30 per cent. at the present time; it was therefore clear that any comparison between the portable engines and the present duty of Cornish engines would not hold good in reference to what the best Cornish engines were capable of doing with good coal. As regarded slow combustion, it must depend very largely upon the quality of the fuel how far this was practicable in each instance; if a boiler were fed with such coal as had been supplied to the mines in Cornwall for the past year or two, it would be quite possible to drive a portable engine with the ashes from it. For instance, he had known as much as 507 tons of coal go through four 10 ton Cornish boilers in five weeks, which was more than

$3\frac{1}{2}$ times what had been mentioned as the proper consumption for boilers of that size, namely 1 ton per day of 24 hours; the ashes from such boilers might consequently be good for firing others.

Mr. Richardson, replying to the various enquiries which had been made, said that, in regard to heating the feed water, it was the general practice in portable engines to employ some sort of feed-water heater, and at Boscaswell Downs the feed water was delivered into the boilers of the portable engines at a temperature of about 110° Fahr., a portion of the exhaust steam being blown through the cistern containing the feed water. In the consumption of fuel by the portable engines, the whole of the fuel consumed, both coal and ashes, had been included; supposing coal only were used, the saving would still be as much as 15 per cent. in comparison with the Cornish engines, and with two thirds ashes and one third coal the saving was fully double that amount. With respect to the duration of the wire ropes used with the portable engines, the particulars given in the paper were the results of actual experience in the working of wire ropes with these engines in a number of different cases: with the smaller engines using drums about 3 feet diameter a steel rope $\frac{5}{8}$ inch diameter was employed to lift a load of $1\frac{1}{2}$ ton; and with the larger sized engines having drums 6 feet or more in diameter a steel rope of 1 inch diameter was generally used to lift loads of not more than 4 tons. In the indicator diagrams taken from the portable engines the rise shown in the back-pressure line in the middle of the return stroke in each cylinder was in consequence of the exhaust from the other cylinder commencing at that moment, the two cylinders being coupled to cranks at right angles; the two diagrams shown by the full and dotted lines in Fig. 11 were taken from the two separate semiportable engines at Boscaswell Downs.

The main point upon which the discussion had turned had been the relative economy of the portable and Cornish engines. In regard to the latter, less had been said about what the Cornish boilers were now actually doing than about what they had done formerly or what they would do under certain circumstances; but for the basis of his calculation with regard to the portable engines

he had taken what they were actually doing, and portable engines were doing 20 per cent. more duty per pound of coal consumed than the Cornish boilers were actually doing. The evaporative duty of the multitubular boiler had been put down in the paper at only $7\frac{1}{2}$ lbs. of water per lb. of coal, in order to be quite within the mark; but the ordinary Cornish boiler did not evaporate more than 5 or 6 lbs. It had been stated in the discussion that in the course of careful experiment the Cornish boiler had given an evaporative duty of 10 lbs. of water per lb. of coal; but in equally careful experiments it was well known that portable engines had given 12 lbs., as in the case of the agricultural trials. It had been said that the same number of men would be needed to work the portable as the fixed engine, and that with the latter a separate fireman was not required; but he knew a number of places where one man had been dispensed with since the substitution of the portable engines. It had also been said that the steam-jacket was no new thing in Cornwall, and of this he was well aware, having been accustomed previously to regard with great veneration the supposed Cornish practice in connection with steam engines and boilers; but he had been much surprised to find on coming into Cornwall that his ideal was not approached by the reality. He had indeed found many engines with steam-jackets, but not many of them had steam in the jacket. As regarded the comparative friction in the two classes of engines, the indicator diagrams exhibited had been taken from engines in actual work, and the friction deduced from these diagrams was accordingly that which actually existed in each case; and though it had been remarked that, as friction was a measure of wear, a Cornish engine losing 50 per cent. of its power in friction must very speedily become worn out, he thought much of the waste of power might be accounted for by the necessity for starting and stopping at each stroke the ponderous mass of the moving parts in the Cornish engine. With respect to the effect of an automatic damper that was obtained in the portable engine by the cessation of the blast when the engine stopped, it had been mentioned on the other hand that there was a damper to the boilers of Cornish engines,

which could be closed when desired; but this required so much extra attention upon the part of the engine driver or fireman, to open and close the damper by hand at the proper times. It had also been alleged that the best engine could not be a non-condensing engine, and he believed the same opinion was pretty generally held; yet the fact remained that, among stationary and portable engines, the best which had yet been tested were non-condensing. In the trials of portable engines by the Royal Agricultural Society, exactly corresponding with the portable engines from which the indicator diagrams exhibited had been taken, the consumption rarely exceeded 3 lbs. of coal per indicated horse power per hour, and in some cases was below $2\frac{1}{2}$ lbs., and there was of course but very little difference in the friction in different engines of that class; such a consumption corresponded to a duty of nearly 80 millions, whereas the present average duty of Cornish rotary engines was only about 42 to 46 millions. Even in compound marine engines, which presented the highest economical results, the greatest economy obtained was a consumption of $1\frac{1}{2}$ lbs. of coal per indicated horse power per hour, and this result was only attained by the employment of very large compound cylinders and other extensive apparatus, with great weight in the moving parts; and he thought if such engines were tested with a friction break in the same way as the portable engines, to ascertain the effective horse power, they would not be found to give a higher duty than the portable engine had given in actual practice. In conclusion he would merely repeat that the calculations respecting the portable engines described in the paper had been based, not upon what could be done, but upon what was actually being done by these engines at the present time.

The Chairman thought that, although opinions widely differing had been given in the very useful discussion raised by the paper, something might be said that would to a certain extent reconcile the discrepancies, so far as the advisability or non-advisability of employing the semiportable engine was concerned; but before touching on this point he desired to make a few observations on the paper itself. Credit appeared to have been taken in it for the

semiportable engine as compared with the Cornish engine, on the ground that the semiportable engine used high-pressure steam and expanded considerably, while the Cornish engine did not use high-pressure steam and did not expand considerably; yet the indicator diagrams exhibited from the semiportable engines showed that these engines were taking steam during 50 and 60 per cent. of the stroke, whereas in the diagrams from the Cornish engine the steam seemed to be cut off at less than 10 per cent. of the stroke, and to give a better expansion curve, unless indeed this were the result of wire-drawing. Certainly he did not agree in considering that the greatest economy was to be looked for in an engine which did not condense. But after saying this, he would pass to the question whether from their simplicity and from other circumstances non-condensing engines of the semiportable class might not be more desirable than others in themselves much more nearly perfect: whether, looking at the first cost of the engine-house and chimney, boiler, and boiler-seating for a stationary engine, the semiportable engine might not be found much more economical in the original outlay, and also in attendance; for although a beam winding engine might occasionally be attended by only one man, he did not think this would be done with so much convenience as in the case of a semiportable engine. These things had to be borne in mind, because it was possible to pay too dearly for even a high degree of apparent economy; for instance, in an engine running twelve hours per day for six days per week, a saving of 1 lb. of coal per horse power per hour amounted to only 34*s.* per horse power per year with coal at its present price of 21*s.* per ton; and however important therefore any small saving in the consumption of coal per horse power per hour might in itself appear, this must be weighed against the increased outlay that would be necessary in the original first cost. He should certainly have liked to see the semiportable engine work with a better indicator diagram than those exhibited; and if the breeches pipe had been made large enough and of such a shape as to allow a free exhaust from one cylinder without interfering

with that of the other, the indicator diagrams would not have shown the sudden rise that was seen in the middle of the return stroke.

A good deal had been said about the economy of Cornish boilers arising from their slow combustion. Having had the honour of being one of the judges, in conjunction with Mr. Menelaus, at the trials of portable engines at the Royal Agricultural Show at Cardiff in 1872, he was satisfied that the high results then stated to be obtained in economy of fuel were accurate and reliable: any errors would certainly have been pointed out by the different rival exhibitors, each of whom naturally watched closely the proceedings of his competitors. The excellent results obtained were due to most careful construction and to the greatest possible attention to the firing,—an attention so great and so costly that it could not be carried out into practice in regular work. As had been stated by the writer of the paper, the firing in those trials took place about every two minutes; the coal was put on with a small shovel resembling a banker's scoop, while the firedoor was opened and shut with such rapidity that it could hardly be followed by the eye. Every skill was exercised to get the most out of the fuel; and this careful firing was the only means by which the full effect of the fuel could be obtained in the fire until proper mechanical means were adopted. The maximum evaporative duty obtained in these trials, under a steam pressure of 80 lbs. per square inch and with Llangennech coal, was equivalent to 11·83 lbs. of water evaporated at atmospheric pressure per lb. of coal from 212° Fahr., or 10·24 lbs. from 62°. The average of all the eleven engines tried was reduced by one very bad example, which evaporated only 4·54 lbs. from 212° or 3·93 lbs. from 62°; but even thus affected the average was 9·85 lbs. from 212° or 8·53 lbs. from 62°. With respect to economy arising from slow combustion, the mean rate of combustion in these trials was 17·6 lbs. of coal per square foot of firegrate area per hour. The maximum was 31·1 lbs., which was in an engine that was doing a very good amount of evaporative duty, namely 9·27 lbs. of water from 212° or 8·03 lbs. from 62°. But the engine which gave the very best evaporative duty consumed as much as 12·8 lbs. of coal per square foot of grate per hour; and another engine that consumed

20·4 lbs. of coal evaporated 10·49 lbs. of water from 212° or 9·08 lbs. from 62°. The slowest combustion was 9·53 lbs. of coal per square foot of grate per hour, and the corresponding evaporative duty was 10·89 lbs. of water from 212° or 9·43 lbs. from 62°. It appeared therefore that within very large limits the rate of combustion of the coal per square foot of grate per hour did not affect the evaporative duty of the boiler. One important point to be attended to was that there should be a sufficient extent of boiler heating surface to absorb the heat developed by the combustion of the fuel: in the Cardiff trials the temperatures in the chimneys of the engines had accordingly been carefully noted, and had been found to be very moderate, ranging from only 320° up to 548° Fahr.; but in two instances the temperature was higher and beyond the range of the thermometer employed.

These high evaporative duties had been obtained with multitubular boilers; and he could not help thinking that, so long as a boiler was properly proportioned, as good an evaporative duty would be obtained from one kind of boiler as from another, and that it was mainly a question of convenience as to which class of boiler should be employed for any particular purpose: provided that due regard were had to the circumstances of each case, such as the cleanliness of the water, and the nature of the heating surfaces, &c., because it would not do, for example, to use a multitubular boiler in places where the water was especially bad. Although they were certainly very high evaporative duties which had been obtained in these portable engine trials, they did not yet by any means come up to the ultimate evaporative power of the coal employed. The Llangennech coal employed was found by analysis to be theoretically capable of evaporating 15·24 lbs. of water from 212° under atmospheric pressure by the perfect combustion of 1 lb. of coal; but the highest duty got out of it in the trials was only 11·83 lbs. of water evaporated, or only 77 per cent. of the ultimate duty theoretically possible. In the case of Ebbw Vale coal the theoretical limit of evaporative duty was 16·8 lbs. of water per lb. of coal. In all questions of evaporative duty it was highly desirable that the ultimate

evaporative power of the fuel employed should be ascertained by analysis, so as to avoid having recourse to any such expressions as "good Welsh" coal, expressions which were altogether too vague to be of any practical service.

With regard to the rotary beam engines used for winding and stamping in Cornwall, he was glad to hear the remarks that had been made in favour of double-cylinder compound engines; and he wished to draw attention to the importance of maintaining a sufficiently high speed of piston in the working of the engines, as he thought in many instances the piston speed was unnecessarily slow. One of the rotary engines at Dolcoath with 8 feet stroke was reported for the month of May last as making 8·9 revolutions per minute, which gave a piston speed of only 142 feet per minute; another at Wheal Margaret with 8 feet stroke was making 7·2 revolutions, which gave only 115 feet per minute. These were the speeds arrived at by assuming that the engines worked continuously from week's end to week's end, without making any allowance for stoppages; but he understood from Mr. Lean that, even when such allowances were made, the increase in speed would not be more than one fourth. On board the steamship "Pera" however, he when recently on a voyage from Brindisi to Alexandria (with a consumption of 1·99 lbs. of coal per indicated horse power per hour) found the piston speed was from 400 to 500 feet per minute. However good the engines employed in Cornwall might be, their utility might be much increased if simply more work were got out of the same machine by letting the pistons go at a higher speed, instead of retarding them to so unusually low a speed as at present. Partly owing probably to this cause, the result of the stamping engines reported by Mr. Lean was not very favourable in respect to economy of fuel, their average duty being only about 40 millions, equivalent to a consumption of $5\frac{1}{2}$ lbs. of coal per effective horse power per hour (1 lb. representing 222 millions duty), the effective horse power being measured by the weight of stamp heads lifted through the height of fall.

In reference to the question that had been raised of the difference between the indicated and the effective horse power of engines,

which difference represented the power absorbed in the friction of the engines, this matter had been tested very carefully in the Cardiff agricultural trials last year. It was there found, bearing in mind that the engines were then being worked at their very best, that an average of $82\frac{1}{2}$ per cent. of the indicated power was really effective upon the break, leaving $17\frac{1}{2}$ per cent. as the proportion of power that was absorbed in friction.

The whole subject of the application of portable engines to mining purposes could not, he thought, be better summed up than in the words of Mr. Amos, who had expressed the opinion that the semiportable engines seemed to afford a ready means for adventurers starting or opening up fresh mines; but when sure of success and with capital at command, then the fixed high-pressure and condensing engines were certainly the best.

Mr. T. Lean mentioned that the highest piston speed in the rotary Cornish engines reported for the month of May last had been 210 feet per minute, in the case of the stamping engine at East Pool mine, with 9 feet stroke making 11·7 revolutions per minute. This speed was the average, including all stoppages; and the allowance for stoppages would probably amount to about one tenth in this instance.

Mr. W. Husband remarked, in regard to the friction of Cornish engines, that in experiments he had made at different times upon stamping engines he had found their friction to be about 20 per cent. or even as high as 25 per cent. of the total power shown by indicator diagrams. In the 36 inch double-acting stamping engine at Great Wheal Vor, near Helston, the friction including the stamps averaged 3·2 lbs. per square inch of the piston, and the total load being about 16 lbs. per square inch, the friction amounted to 20 per cent. of the power in that case. With the compound engine employed to drive the pneumatic stamps, the friction including the stamps was found to be about 15 to 20 per cent. of the indicated horse power; and he had found the friction of Cornish pumping engines, including the pumps and rods, varied from 25 to 45 per cent. of the total indicated horse power.

Mr. FROUDE observed that he had had occasion to investigate very carefully the friction of the engines in the case of the steamship "Rattler," the first government ship with a screw; and there was found to be on an average 25 per cent. loss of power in friction, the thrust realised in the screw representing only 75 per cent. of the indicated horse power in the steam pressure upon the pistons.

The CHAIRMAN proposed a vote of thanks to Mr. Richardson for his paper, which was passed.

The following paper was then read :—

Table showing DUTY *reported of* CORNISH PUMPING ENGINES *during sixty-two years from* 1811 *to* 1872.
(*See page* 190, *and Figs.* 13 *to* 15, *Plate* 66.)

Year.	Average number of Engines reported.	DUTY. Millions of ft.-lbs. per cwt. of coal.		CONSUMPTION. Lbs. of coal per effective horse power per hour.	
		Average.	Highest.	Average.	Lowest.
	No.	Millions.	Millions.	Lbs.	Lbs.
1811	12	20·4	—	10·87	—
1812	21	22·9	—	9·68	—
1813	29	23·2	34·1	9·56	6·50
1814	32	24·5	41·7	9·05	5·32
1815	35	24·4	62·1	9·09	3·57
1816	35	27·4	67·7	8·06	3·28
1817	35	31·5	62·3	7·04	3·56
1818	36	30·2	56·5	7·34	3·92
1819	40	31·3	57·7	7·08	3·84
1820	46	34·1	60·0	6·50	3·70
1821	45	33·7	57·0	6·58	3·89
1822	52	34·4	56·2	6·45	3·95
1823	52	33·6	60·7	6·60	3·65
1824	49	33·7	55·8	6·58	3·97
1825	56	38·1	57·4	5·82	3·86
1826	51	36·3	59·4	6·11	3·73
1827	51	38·2	79·8	5·81	2·78
1828	57	44·2	103·6	5·02	2·14
1829	53	49·6	97·5	4·47	2·27
1830	56	51·5	92·8	4·31	2·39
1831	58	51·7	92·1	4·29	2·41
1832	59	53·6	108·7	4·14	2·04
1833	56	55·5	105·4	4·00	2·10
1834	52	56·9	116·5	3·90	1·90
1835	51	56·9	114·0	3·90	1·95
1836	61	55·5	116·1	4·00	1·91
1837	58	56·0	109·4	3·96	2·03
1838	61	58·0	109·0	3·82	2·03
1839	60	63·0	101·2	3·52	2·19
1840	59	64·8	101·5	3·42	2·18
1841	52	65·0	121·4	3·41	1·83

A Consumption of **1** lb. of coal per effective horse power per hour is equivalent to a Duty of **222** (221·76) million ft.-lbs. per cwt. (112 lbs.) of coal.

Table (continued) showing Duty *reported of* Cornish Pumping Engines *during sixty-two years from* 1811 *to* 1872.
(*See page* 190, *and Figs.* 13 *to* 15, *Plate* 66.)

Year.	Average number of Engines reported.	DUTY. Millions of ft.-lbs. per cwt. of coal.		CONSUMPTION. Lbs. of coal per effective horse power per hour.	
		Average.	Highest.	Average.	Lowest.
	No.	Millions.	Millions.	Lbs.	Lbs.
1842	45	64·1	127·9	3·46	1·73
1843	40	67·0	125·9	3·31	1·76
1844	35	65·1	117·6	3·41	1·89
1845	36	66·1	114·3	3·35	1·94
1846	28	63·1	107·5	3·51	2·06
1847	27	63·1	108·7	3·51	2·04
1848	27	63·0	104·4	3·52	2·12
1849	26	63·6	95·3	3·49	2·33
1850	26	61·8	90·1	3·59	2·46
1851	24	60·0	82·8	3·70	2·68
1852	17	59·2	79·2	3·75	2·80
1853	20	57·1	74·7	3·88	2·97
1854	21	53·6	77·0	4·14	2·88
1855	18	54·8	75·3	4·05	2·95
1856	23	54·9	93·0	4·04	2·38
1857	18	51·4	98·3	4·31	2·26
1858	16	52·4	73·4	4·23	3·02
1859	23	50·7	89·6	4·37	2·47
1860	23	51·6	82·6	4·30	2·69
1861	27	51·5	75·3	4·31	2·95
1862	31	51·6	79·1	4·30	2·80
1863	30	51·7	77·4	4·29	2·87
1864	34	51·3	77·7	4·32	2·85
1865	33	50·2	78·4	4·42	2·83
1866	26	50·5	78·4	4·39	2·83
1867	23	52·3	78·2	4·24	2·84
1868	23	51·2	75·3	4·33	2·95
1869	19	49·8	78·0	4·45	2·84
1870	19	51·2	75·4	4·33	2·94
1871	21	54·7	82·8	4·05	2·68
1872	20	51·4	76·5	4·31	2·90

A Consumption of **1** lb. of coal per effective horse power per hour is equivalent to a Duty of **222** (221·76) million ft.-lbs. per cwt. (112 lbs.) of coal.

DESCRIPTION OF A MACHINE FOR SHAPING THE MODELS USED IN EXPERIMENTS ON FORMS OF SHIPS.

By Mr. WILLIAM FROUDE, F.R.S., of Torquay.

In the construction of Models illustrative of the Forms of Ships, the ordinary mode of procedure is to build up the model in a series of horizontal layers of uniform thickness, consisting of boards of that thickness cut to the form of the intended water lines at the corresponding successive levels as laid down on the drawn plan of the vessel; and the exterior of the model is finished by dressing off the edges of the boards to a fair face. This mode of construction however, though well suited for a permanent model of small size to represent an executed ship, would be both costly and tedious, where the object is to investigate the results of an extensive series of large models, the forms of which have to be successively modified according to the results obtained from the experiments as they proceed. In such cases it is an important object to have the means of readily, expeditiously, and economically creating new models, and of modifying in some portion the lines of one already made, without affecting the remainder and without losing the original; and in the ordinary method this could only be effected by the expensive and tedious process of drawing out and shaping a complete set of profile boards for a new solid wood model.

In order to accomplish both these objects without encountering the usual difficulty, it occurred to the writer that in a solid body of suitable material, already roughly shaped to the intended form, the series of correct water lines might be produced by means of a pair of revolving cutters working symmetrically, one at each side, and guided by a series of templates of small scale, on the principle of curvilinear shaping machines.

The profiles of the templates too, instead of being cut in solid material, might be formed of flexible bands, each of which might be set to the line required in originating the successive models : the same templates thus serving to represent successively an indefinite number of variations in form. This object has been accomplished with complete success in the machine forming the subject of the present paper; and the writer has been enabled by this means to commence a very extensive series of experiments on the resistances of various forms of vessels,—comprising when completed the results of several hundred models of large size,—which would have been quite impracticable with the ordinary construction of models, on account of the great length of time and heavy expenditure that would have been requisite.

To find the suitable material was the most important point of all. Wood, the material commonly used for models, besides being unnecessarily hard for the purpose, and, from its unequal texture, not readily taking a smoothly polished surface, would require a considerable expenditure of time and labour in the mere conversion of plank into a hollow body of a shape reasonably approximating to that of the intended model. Also the expense of the consumption of wood alone would be very serious for the great number of models required in an exhaustive series of experiments. The material best suited for the purpose would clearly be one, which, though hard enough, would cut freely and smoothly in any direction, without requiring much power and without blunting the tools; a material fusible at a low temperature, so as to be easily cast approximately to the shape required; of not great specific gravity; impenetrable to water without the application of any artificial coating; and, above all, capable of being melted up again repeatedly to form new models. Almost the first material that suggested itself—hard paraffin—was found to fulfil every one of these conditions. Indeed qualities could hardly be specified, not obviously inconsistent with one another, which are more fitted for the purpose required than those possessed by this material. It is no doubt rather costly in the first instance; but since it allows all the cuttings taken off in the process, as well as all the experimental models that are

not needed for further trial, to be used again by being remelted, the total stock required is reduced to a very small amount.

The models are generally about 10 feet long, made hollow with about $1\frac{1}{2}$ inch thickness when finished, and weighing then about 200 lbs. The mould is formed of plastic clay, contained in a fixed rectangular box, and is wrought into shape in accordance with rough transverse templates representing the intended exterior of the model, with due allowance for cutting; these are guided into position by suitably placed notches cut in a pair of level parallel strips, which lodge in a pair of horizontal longitudinal channels formed in the top sides of the box. The same notches serve afterwards to guide into place a corresponding set of rough transverse templates representing the interior of the model, with the core formed on them. This is shaped by open-planking the templates with thin wood laths, so as to form a boatlike skeleton, and is then smoothly skinned over with calico, rendered practically paraffin-tight and water-tight by painting on it a double wash of softened clay, with an intervening wash of plaster of paris. The melted paraffin is run into the space between the mould and the core, and as the buoyancy of the core would often exceed 800 lbs., it is loaded down partly with ballast, and partly with cold water run into the interior as the paraffin rises outside, so as nearly to equilibrate the fluid pressure of the latter and at the same time to assist its cooling.

The Machine for Shaping the Models is shown in Figs. 1 to 4, Plates 67 to 69, Fig. 1 being a side view, Fig. 2 an end view, and Fig. 4 a plan, all partly in section.

The paraffin model M to be shaped is carried on a travelling table A, Figs. 1 and 2, analogous to that of a planing machine, and rests inverted upon it. It is kept in its place by two stout pins in the centre line of the table, $3\frac{1}{2}$ feet distant from each other; these govern the position of the model by fitting into two beams, which are fastened across the model from gunwale to gunwale, being there fixed by screws to wood blocks cast into the sides of the model for the purpose, as shown at B in Fig. 2. These beams remain in

the model when finished, so that besides forming the guidance for "chucking" the model whenever it is placed on the shaping machine, either for shaping in the first instance or for alteration afterwards, the holes in the beams serve also to fix truly central on the model a frame furnished with all the fittings necessary for the subsequent towing experiments for which the model is designed. The travelling table A rests on a four-wheeled body-frame, being supported by four vertical screws D D, which are stepped in the frame, and are geared together by bevil wheels and coupling rods, so that by the rotation of one handle the table with the model on it can be raised to successive heights, continuing perfectly level throughout. The wheels, 12 inches diameter, run upon rails that are planed and truly levelled on the face; the two wheels on one side are double-flanged, and thus the guidance is given by a single rail, so that there is no risk either of undue tightness of gauge or of undue play; the whole is accurately fitted, so as to ensure a perfectly steady, straight, and parallel movement of the machine with the model.

The model is shaped by a pair of revolving cutters C C, Figs. 2 and 3, one on each side, revolving at a high speed (about 1500 revolutions per minute) on vertical spindles, which are carried in sliding frames E E that have a horizontal transverse movement exactly at right angles to the longitudinal motion of the travelling table A with the model. The sliding cutter-frames E have each a large area of base, sliding upon a pair of guide bars F F, so as to ensure a perfectly steady support for the cutters in every position; and they are so coupled together that their movements are exactly equal but in opposite directions, the two cutters being kept always equidistant on each side from the centre line of the model M, Fig. 2.

Longitudinal travel is given to the model by the operator by means of the handwheel G, Figs. 1 and 2, carrying a cord which is fixed to each end of the travelling table A; and whilst the model passes through between the cutters C, these are made each to copy upon it the desired water line from the small-scale template H, Fig. 1, which travels proportionally to the model, the two cutters being traversed simultaneously towards or from the centre line in

careful accordance with the profile of the template. The manner in which the template regulates the travel of the cutter-frames is as follows. Two bell-crank levers L L, Fig. 2, have their vertical arms coupled by horizontal links to the sliding cutter-frames E, and their horizontal arms coupled by vertical links to a central bar K sliding vertically in fixed guides; the lengths of the two coupling links are made in the same proportion as the two unequal arms of the bell-crank levers, so as to make the horizontal travel of the cutters correctly proportionate throughout to the vertical travel of the sliding bar K. This condition is, as will be seen, essential to the truth of the copying action; for the vertical travel of the central sliding bar K is proportionate to the vertical travel of a parallel tracer bar N sliding in vertical guides, the lower end of which carries the tracer J, Fig. 1, that has to follow the curve of the template H. The connection between the sliding bar K and the parallel tracer bar N is a horizontal lever P having its fulcrum between the two, and having one end attached by a pin joint to the central bar K, while the other end passes through a mortise in the tracer bar N; and as this arrangement involves a sliding action both at the fulcrum and at the tracer bar, the pressure is delivered through a friction roller in each case. The bearing surfaces of the lever P which rest upon the rollers are planed parallel, and the lever is cranked, as shown in Fig. 2, so as to bring the centres of the two rollers into the same straight line as the pin joint; by this arrangement is obtained the first step towards the truly parallel copying movement, namely the maintenance of a constant proportion between the vertical movement of the tracer bar, and the horizontal movement of the centre of the circular sweep of the cutters. By shifting the position of the fulcrum roller, which is done without disturbing the accuracy of the copying movement, it is easy to adjust the proportion between the transverse scale of the model and that of the template to any desired fractional amount.

The actual force which causes the cutters to traverse inwards or outwards is not transmitted through the copying lever P, nor is any duty but that of indication performed by the tracer J and

template H; but the force is conveyed direct to the sliding bar K by a large overhead lever Q, Fig. 2, worked by a rod and hand lever R in a convenient position; and the extent of the traverse is limited by the contact of the end of the tracer bar with the template, which is accurately noted by the operator by means of a special arrangement described afterwards. The friction of travel of the cutter frames is reduced to a minimum by the expedient of counterpoising their dead weight, by means of the suspending slings and counterbalance weights O, Figs. 1 and 2; and the tendency of the cutters to make the frames E vibrate in and out along their guides, and also to lay hold of the model and bite too deep, is checked by a large oil cylinder or cataract S applied to the central lifting bar K.

Each cutter spindle is driven by a catgut belt carried round a grooved sheave at its upper end, and passing out sideways to leading pulleys in the main uprights of the machine frame, and thence to a sheave T on an overhead shaft driven by a small steam engine. With this arrangement the transverse travel of the cutter frames necessarily requires an elongation or shortening of the catgut belt; and therefore "jockey" pulleys U, sliding vertically and sufficiently loaded to communicate the requisite tension to the belt, are provided to take up and give out the necessary slack. The tension on the two parts of the belt leading off sideways from the cutter spindles necessarily produces a considerable and nearly constant force tending to make the cutter frames separate from each other; and this is counterbalanced by a sufficient weight W hung on the outer end of the overhead lever Q. This arrangement has the advantage that, since the pull of the belt is far greater than the friction of the sliding cutter-frames on their guide bars, the bell-crank system is always, so to speak, in tension, and consequently any error that might arise from "lost time" in the pin joints is entirely obviated.

The mode in which the templates are made changeable in form, so that one set of templates can serve for any number of different models in succession, is by employing a thin flexible steel ribbon to

form the profile of the template. Each template when set to the required curve represents a full-length half-plan of one of the water lines of the intended model. One of the templates is shown to a larger scale in Figs. 7 and 8, Plate 70. The steel ribbon V is held to the required curvature by the outer ends of a series of square steel rods X, which act somewhat as ordinates, having their inner ends held by what may be called a mortised straight-edge Y; the mortises are made wide-mouthed, so that the rods have free play in the plane of the straight-edge, at the back of which they pass through rocking collars with clamping screws that control only the elongations of the rods. At the outer end of each rod is a narrow hinge, with its motion in the plane of the straight-edge, and with one flap soldered to the rod, while the other is cut short and is held to the steel ribbon V as an internal tangent by a small screw with a narrow flat head. The ribbon is punched along its centre line with a series of holes, which are closely spaced to prevent localised flexure and to allow the rod ends to meet it in any desired positions, the rods being generally slanted so as nearly to be internal normals to the curve, and thus best to define its form. The set of templates being thus prepared for the successive water lines of the model, the first one is fixed vertically upon a sliding frame at the side of the shaping machine, as shown at H in Fig. 1, with the curved face of the steel ribbon uppermost; and the tracer J is brought down upon it, and made to follow its curve whilst the template travels under the tracer simultaneously with the traverse of the model. The template is only 3 feet long, for convenience of construction and drawing out the curves; so that its motion is only about one third that of the models of average length, and the exact proportion of the motion is adjusted by means of a set of change wheels Z. Thus the arrangement which governs the ratio of the length of the model to the length of the template is independent of that which governs the ratio of their breadths; and this condition makes it possible not only to have the transverse scale of the template larger than the longitudinal, thereby lessening the relative errors in copying breadth, which is at once the smaller and the more important dimension, but also to cut with one

set of templates a series of models, in which, while the ratio of length to breadth is varied at pleasure, the general character of the lines is the same in all.

As the cutters describe a circle of 3 inches radius, it is necessary that the end of the tracer should be not a point, but a figure analogous to the circle, that is to say an ellipse, consisting of the circle of the cutters compressed longitudinally according to the longitudinal scale of the template, and compressed transversely according to its transverse scale. The steel ribbon that forms the template is very flexible, being only 1-100th inch thick; and it is consequently necessary to provide against any pressure of the tracer upon it. This would be impossible to prevent, if the felt contact of a rigid tracer with the template were employed as the means of guidance; and it would be almost impossible by eye to keep the tracer in exact contact with the template, yet without pressing upon it. The arrangement employed to obviate this difficulty is shown one third full size in Figs. 5 and 6, Plate 70. The tracer J, standing directly under the tracer bar N, is mounted at one end of a light arm A, which has a certain range of motion in a vertical plane, being delicately pivoted on a bracket carried out horizontally from the end of the tracer bar N; the other end of the arm is counterpoised so as to be all but equivalent to the tracer end, which thus forms a sensitively self-extending termination to the tracer bar, resting with a very small but perfectly uniform pressure upon the template. The variations of extension are exhibited on a greatly magnified scale by a small index-pointer I, which when at its zero shows that the tracer J occupies its normal position with relation to the bar N, the arm A being connected with the index-pointer I by a fine thread. In setting the machine for work, the parts are so adjusted that when the cutter frames are advanced till the cutter circles touch and form a zero of breadth to the model, the tracer shall rest on the centre line of the template with its index-pointer at zero. In the working of the machine thus set, the operator advances the cutter frames by depressing the handle R, Figs. 1 and 2; the tracer, hanging down a little in advance of its normal position, "strikes soundings" (so to speak) on the template, and

by the immediate rise of its index-pointer gives him early warning of the advance of the cutters towards their proper cutting depth; and he arrests it when the pointer is at zero.

In practice it is found most convenient to commence each cut near the greatest breadth of the model, and work towards one end; and then to return to the middle and work thence to the other end, it being more easy to follow the template when the breadth is constantly decreasing. It is also found better, having brought the cutters to the correct ordinate for the position of the model, to travel the model about half an inch without moving the cutter frames; then to bring in the cutters to the diminished breadth, then move the model again, and then the cutters again: thus proceeding by a series of minute motions, first of abscissa and then of ordinate, instead of trying to follow the curve of the template by a perfectly continuous motion.

After one water line has been thus cut from end to end—an operation taking about five minutes—the model is raised through the necessary vertical distance by turning the elevating screws of the table, and the template is exchanged for the one prepared for the next water line above, which is then cut; and so on until all the water lines have been copied upon the model, which then presents the appearance of a series of steps or terraces analogous to those formed by the edges of the boards that make up a wood model of the ordinary construction. As in the wood model, the finishing has now to be done by dressing off these prominences by hand, till the cross sections of the model are fair curves, the inner angle of each step being only just obliterated. Before commencing the final dressing however, a spur tool is travelled along these inner angles, making in the surface small punctures of alternately infinitesimal and sensible depth, which are then filled with black lead. The shallower of these may be more or less obliterated in the finishing; the deeper should all show in the finished surface when the model has been correctly trimmed off, and serve thus as a "witness" or guarantee of the truth of the work.

The final shaping is done with flexible steel straight-edges used as scrapers, which follow all the curvatures of the surface and ensure its fairness. The surface is then burnished all over by using a very blunt tool with considerable pressure; this fills up all the minute pores, of which the paraffin is always found to be full except near the skin of the casting, and which if left open would constitute a sufficient roughness of surface to produce a sensible increase in the resistance of the model. After the burnishing, the flexible scrapers are again passed over the surface with a light touch, so as to obliterate the slight marks of "chatter" of the burnishing tool; and this final scraping brings the material to a beautiful polish, like that of marble.

A remark may here be added about one use of the collection of flexible templates, which may not at once suggest itself. Supposing these to be laid down and piled in order one on another, with their centre lines and the corresponding portions of their length in correct superposition; and supposing their thickness (that is, the breadth of the steel ribbon) to be equal to the vertical interval between the water lines, reduced to the scale of the templates: it will be obvious that if the series of steps so formed were filled up with clay, and the whole then trimmed off with a fairly rounded surface till the upper edges of the ribbons became just apparent, there would thus be obtained a small-scale and foreshortened counterpart of the intended model, placed bottom upwards. This property greatly facilitates the process of designing new forms; for it is readily possible, by bending a slim batten over the upper edges of the templates when thus placed in combination, to discover whether the set of water lines they represent will produce fair cross sections; and if not, to apply the necessary corrections at once, without going through the tedious process involved in arriving at this result by drawing. Also the mere aspect of the combination of templates so fully conveys to the mind the figure of the completed model, that it enables the designer to develop many useful variations of form without any drawing at all.

For the purpose of thus placing the templates in correct superposition, a table is provided, furnished at each end with a vertical "chase," into which the ends of the straight-edges carrying the steel ribbons are cut to fit exactly. The sliding board H, Fig. 1, Plate 67, at the side of the cutting machine, has blockings fixed on it, which are shaped to fit the same parts of the templates.

Mr. Froude exhibited a portion of one of the paraffin models shaped by the machine, showing the series of successive cuts. He remarked that the subject of experiments with accurate models as to the value of different forms of ships was a very important and extensive one; and the series of experiments that he had entered into was on behalf of the Admiralty, by whom the means were supplied for the purpose. The great success of the machinery employed was the result of the combined thought of several minds, whereby the system had been matured into its present very perfect state, enabling the shaping of the models to be done with very great accuracy. The displacements were always calculated beforehand, and when the models were put into the water they were loaded according to the calculated displacements, which were found to come out correct within less than 1-500th. Indeed it would certainly be considered there was something wrong in the model, if when properly loaded the addition of only $\frac{1}{2}$ lb. weight would not make it deviate sensibly from the flotation line calculated for it.

With regard to the material employed for the models, any one trying to cut the specimen exhibited with a knife or a spoke-shave would see how easily the paraffin cut, although it looked like marble. It had occasionally happened that persons visiting the workshop, sometimes even artisans, had been misled by the appearance of the models into the idea that they were made of

marble. The cutting of the paraffin was so easy that with the smoothing plane shavings were taken off not more than 1-1000th inch thick, and they came off perfectly clean, without choking the plane, and looked just like drifted snow. The lightness of the shavings had really formed a serious difficulty at first, and it had been necessary to provide curtains for covering the model completely while the shaping was being done by the machine, in order to prevent the light cuttings from flying about the whole workshop.

One of the most interesting points in the machine was in regard to the templates, and the follower by which their outline was traced. The action of the follower was extremely sensitive, its weight being counterbalanced so as to leave only just preponderance enough to keep it barely in contact with the template; there was therefore no risk of its pressure deflecting the steel templates in the smallest degree, although the latter were only 1-100th inch thick and the slightest deviation from their correct curvature would spoil the accuracy of the model. The time occupied in preparing the clay mould and casting the model was one day, and the model was cold enough next day for shaping, which also occupied about a day; each model when its work was done was melted down again for casting afresh. Very often the same model was put upon the machine several times, to have small variations in form given to it. He invited any of the Members, who might be able to do so, to call at Chelston Cross when passing Torquay in returning from the Cornwall Meeting, so as to see the operation of the machine at work there.

Mr. E. Easton said that having had an opportunity of seeing the machine he advised all the Members who possibly could to take advantage of Mr. Froude's kind invitation and see it for themselves. He was particularly struck with the remarkable accuracy stated to be attained in the shaping of the models; as these had some of them a total displacement of 600 lbs., and were usually about 10 feet long, the circumstance that so small a difference as only $\frac{1}{2}$ lb. in their displacement was clearly apparent

showed the extreme accuracy with which they were shaped. He enquired what was the largest size that had been made of the models.

Mr. Froude replied that the largest size that had been made was 12 or 14 feet length, and the machine was capable of shaping a model 16 feet long.

Mr. Jeremiah Head asked what was the chemical composition of the paraffin employed for the models; it certainly was not an elementary substance.

Mr. B. C. Tilghman replied that paraffin was the solid portion derived from the distillation of bog coal or bituminous shale; it was also present in large quantities in the petroleum and other rock oils of Pennsylvania. It was a hydro-carbon, not capable of being affected by any chemical agents, either acids or alkalis; even the strongest sulphuric or nitric acid produced no effect upon it, and its want of affinity was the reason of the name given to it.

Mr. Froude said the models were all made of pure white hard paraffin, the cost of which was at first 8*d.* per lb., but was now more than a shilling. The surface of the paraffin, as left by the cutting tool of the shaping machine, was somewhat rough and porous, on account of the coarsely crystalline texture of the material; and as a close smooth surface was particularly wanted, it would be very desirable if something could be found that would act as a solvent upon the paraffin, so as to dissolve it and admit of its being applied as a varnish upon the models.

Mr. B. C. Tilghman suggested that the formation of a crystalline structure in the paraffin might be prevented by the addition of a small quantity of wax, and by constantly stirring the melted mass as it cooled, until it became like thick cream, and then pouring it into the mould previously warmed. Or by passing a gas flame rapidly over the cut surface of the model, so as to melt a thin superficial film of the paraffin which would instantly solidify again, a smooth close skin might probably be produced.

Mr. Froude said he had not tried mixing wax with the paraffin, as his object had been to avoid the use of wax on account of the stickiness it would introduce into the material, making it

cling to and muffle the edges of the tools and thus work less freely; the freedom of paraffin from stickiness was in this aspect one of its great merits. The strength of the paraffin models was so great that it required good hard blows with a sledge hammer to break a model up for remelting; but if it were kept for some time in a position in which it was subjected to unequal strains, even though slight in amount, it became distorted; so that if a model were wanted to be preserved for further use, this was done by water-logging it, whereby it was kept entirely free from strain, the specific gravity of paraffin being very little below that of water.

The CHAIRMAN observed that the paper which had been read was very complete and clear; it gave the impression that all difficulties had been solved, and in the most satisfactory manner. Other important investigations were being carried on by Mr. Froude, as to the rolling motion of waves and the exact behaviour of ships with regard to them; and he trusted these investigations would result in ships being designed and built upon correct scientific principles that might be relied on. A remarkably ingenious instrument for recording the real as distinguished from the apparent rolling motion of ships had very recently been contrived by Mr. Froude, who had at the Institution of Naval Architects been rightly congratulated upon possessing not only the ingenuity to contrive but also the manual skill to execute that which he designed. He (the Chairman) hoped many of the Members would avail themselves of the opportunity of visiting Mr. Froude's workshop at Chelston Cross, where there were so many things to be seen that were of the greatest interest for mechanical engineers. He moved a vote of thanks to Mr. Froude for his paper, which was passed.

The following paper, communicated through Mr. Henry T. Ferguson, was then read:—

DESCRIPTION OF THE MECHANICAL SCRAPER FOR REMOVING INCRUSTATION IN THE MAINS OF THE TORQUAY WATER WORKS.

By Mr. JOHN LITTLE, of Torquay.

The supply of water for the Torquay Water Works is obtained from a reservoir at Tottiford near Dartmoor, and is brought a distance of $14\frac{1}{2}$ miles along the course shown by the dotted line W on the map in Plate 22, through a cast-iron main that is 10 inches diameter for the first 8 miles to Newton and 9 inches diameter from thence to Torquay. This main delivers into one of the service reservoirs outside the town of Torquay at a level 465 feet below the supply reservoir, and 250 feet above sea level; it also delivers into another service reservoir 400 feet above sea level for the supply of the higher districts; the water is turned into the lower reservoir for fourteen hours, and into the higher one for ten hours each day. The main follows the levels of the ground throughout its length, being sunk uniformly 3 feet below the surface, as shown in the general section and plan, Figs. 1 and 2, Plate 71.

After the whole had been in operation only a few months, it was found that the rate of supply obtained from the main at the service reservoir was much reduced below the original supply; and this reduction extended so seriously that after a year's work the quantity of water obtained was less than 50 per cent. of the original supply. The cause was found to be a rapid accumulation of incrustation within the pipes, arising from a very unusual extent of oxidation; and on examination of the water the quality was found to be very pure and of unusual softness, containing only 3·1 grains of solid matter per gallon. The incrustation of oxide formed a coating over the whole interior surface of the pipes, and accumulated in nodules that occasionally

extended to $\frac{1}{4}$ inch thickness, and may possibly have diminished the average diameter of the pipe by $\frac{1}{8}$ inch; and the consequence was an obstruction of the water flow, not so much from reduced area of passage, as from the great roughness of the interior surface of the pipes. The result was so serious in the deficient supply of water and in the prospect of its further diminution, that the question of incurring the heavy expense of laying down a fresh main of larger size had to be taken into consideration.

The incrustation formed in the pipes is of a soft description, and readily removable by mechanical means; and a happy suggestion was made by the late Mr. Appold to employ a Mechanical Scraper fitting within the pipe, and propelled by the water passing through the pipe, so as to scrape off the incrustation as it passed along. This idea was warmly supported by Mr. Froude, who aided actively in carrying it into effect; and although great doubt was generally felt as to the practicability of the plan, it was determined to make trial of it upon a length of nearly a mile of the 10 inch main.

The Scraper employed, as first designed by Mr. Appold, is shown in Fig. 3, Plate 72, and was of very simple construction, consisting of two pairs of flat steel arms A A bent backwards, and curved outwards at their back ends to form scraping knives; each knife extended in breadth rather more than an eighth round the circumference of the circle, and another similar set of four knives was fixed behind and in an intermediate position, filling up the circle, so that the entire circumference of the pipe was scraped by their passage. The elasticity of the steel arms kept the knives pressed outwards against the sides of the pipe, but allowed them to yield to the irregularities met with at the joints and elsewhere in passing through the main. The whole scraper was propelled by means of a piston B in the rear, consisting of a deep cup with elastic sides pressed outwards against the pipe by the pressure of the water behind. The piston was not intended to fit closely in the pipe, but merely to obtain a sufficient excess of pressure

behind for overcoming the resistance of the scraping knives; and the portion of water that escaped past the piston was required for carrying away the material as fast as it was scraped off.

The result of the first trial was a complete success, and the scraper passed slowly through the whole length of pipe under trial without any stoppage or difficulty occurring. Considerable anxiety had been felt about the risk of the scraper sticking fast in the pipe, and the necessity that would then arise for finding out its situation and cutting open the pipe to remove it. A special provision was therefore made for ascertaining the position of the scraper at all times during its passage through the pipe, by attaching a small cord to the back of the piston; this cord passed out through a stuffing-box in the side of the pipe, and was drawn off a counting wheel for measuring the length delivered out. On trial however this precaution was found to be unnecessary, for although the pipe was buried three feet deep in the ground, the sound of the scraping was so distinctly audible that the progress of the scraper could be accurately followed by men walking along over the line of the main.

The effect of once passing the scraper through this trial length of nearly a mile was an increase of four gallons per minute in the delivery of the whole main of $14\frac{1}{2}$ miles length; and it was determined consequently to extend the operation to the rest of the main, but it was found that an improved scraper was necessary. Another scraper suited to both the 10 inch and the 9 inch main was designed by Mr. Froude and Mr. Box, after the death of Mr. Appold; but although this improved scraper was better than the original one, still it did not work satisfactorily.

In the first application of the scraper to the whole length of the main, an unexpected and very troublesome cause of stoppages was met with in the presence of a number of stones, which must have been dropped in at the time the pipes were laid; and it was found requisite to employ a special tool for clearing the main from stones before the scraping could be completed. This tool is shown in Fig. 4, Plate 72, and consisted of a deep cast-iron cup C propelled through in a similar manner previously to the scraper, and having a bevilled edge in front; the outside of the cup was about $\frac{3}{8}$ inch clear from

the sides of the pipe. Great difficulty was however experienced in carrying on this operation; the piston of the cup was several times jammed by the accumulation of the stones in front of it, and it was found necessary to cut open the main frequently for releasing the cup, which stuck fast sometimes after traversing only a short distance, and this occurred at places where there was not any apparent cause of obstruction. Ultimately the cause was found to be that the sides of the deep cupped-leather of the piston, which was of the form shown at B in Fig. 3, were held so tight against the pipe by the pressure of the water behind that the piston became jammed fast by its adhesion. The great length of this piston had been adopted for passing the openings of the air vessels on the main; and the improved form of piston shown in Fig. 4 was then tried, consisting of two separate short pistons D D, placed at such a distance apart that one would always be past any opening before the other came up to it. Each piston D consists of a flat leather disc rubbing against the pipe at its edge, supported by a plate in front, and stiffened at the back by segment plates riveted on, as shown in Plates 73 and 75; the piston leathers of all the scrapers are made $\frac{1}{2}$ inch larger than the diameter of the pipe, but in a short time become worn down to the size of the pipe; and in order to save the trouble of constantly attaching the back segment plates to new leathers, a second disc of leather, 1 inch larger in diameter than the pipe, is inserted between the first leather and the front plate. The piston is protected in front by a cup-shaped guard E, Figs. 5 to 12, fixed to the back of the scraper and formed of thin flexible steel segments. The pair of pistons is connected with the scraper by a rough sort of universal joint F. This make of piston has proved quite satisfactory, and continues in use without alteration.

The scraping knives, as originally made, were only capable of moving radially inwards by the yielding of the spring arms A A, Fig. 3; but this was found to be an insufficient provision for irregularities in the pipes, and in the case of the edge of a joint projecting inwards it was necessary that any knife catching against it

should also be able to yield backwards in order to prevent a stoppage. An improved scraper was designed for this purpose by Mr. Froude, having each of the knives fixed upon a separate arm which worked upon a transverse pin and was supported by a spring, so as to allow the knife to yield backwards as well as inwards on meeting any obstruction. The matured scraper on this plan as finally adopted for use is shown in Figs. 5 to 8, Plates 73 and 74. Each knife J is on the end of a short arm G, which is centred on a transverse pin and is pulled forwards by a longitudinal spiral spring H exerting a pull of about 60 lbs. upon the knife, and allowing it to give way backwards when meeting any solid obstruction such as a projecting joint. The whole is carried on a longitudinal bar L that is centred at the front end and pressed outwards by a flat spring K, which presses the knife against the side of the pipe, but is prevented by a stop I from passing beyond the size of the pipe. There are six knives, each of them with the two springs and joints as above, and placed in two sets of three, alternating with one another round the circumference of the pipe. In the first of the improved scrapers only four knives were tried, for the purpose of reducing the number of parts; but each knife had then to extend as far as one quarter round the circumference, and its extremities consequently came too near the centre of motion of the knife arm for allowing a sufficient range of motion to clear an obstruction, and six knives of two thirds the former width were consequently adopted. The scraping edges of the knives are made wedge-shaped, sloping back on each side from the centre, as shown in Fig. 5, for enabling them to pass freely over any small opening, such as a joint not fitting close.

This improved form of scraper is found completely successful, and has proved so effective in overcoming all the difficulties of working, that on the last occasion of scraping the 10 inch main from the supply reservoir to Newton the whole distance of eight miles was traversed continuously by the scraper without a single stoppage, and within a period of five hours. The rate of working indeed has now to be limited by the speed at which the scraper

can be followed by the men in attendance, so as to ensure that its position in the main is never lost. A party of six men follow the passage of the scraper when it is started in the pipe, each one in succession noting the sound of the scraper by lying on the ground, and taking a fresh position in the front as soon as it has passed him. As the main is laid across the rough moor, the rate of progress for the men is necessarily limited, and the speed of traverse of the scraper has to be regulated by checking the driving pressure by means of the stop and waste sluices in the main.

For starting the scraper from the beginning of the pipe at the Tottiford reservoir, the stop valve is shut at the summit of the first rise in the line of main, at C in the section Fig. 1, Plate 71, and the wash-out cock at B is opened at the bottom of the intervening valley 180 feet below the level of the reservoir, the scraper having been inserted at A at the beginning of the pipe; a vacuum is thus created in the upper part of the pipe, by means of which the scraper is drawn along in the pipe until the pressure of water behind it is sufficient to propel it. By experiment with a spring balance it was found that a pull of about 280 lbs. was required to drag the scraper through two dry lengths of corroded 10 inch pipe, put together intentionally with a bad joint out of line; this force is equivalent to a head of about 8 feet in a pipe of 10 inches diameter. Much of the success that has at last been attained in the application of the scraper is due to Mr. Weeks, the Water Bailiff to the Board, who has not only suggested many of the alterations of the scraper, but has been actively engaged in carrying out the scraping operations from the commencement, and in overcoming the numerous practical difficulties that were met with in the successive attempts.

The scraping of the whole length of the $14\frac{1}{2}$ miles of 10 and 9 inch main has now been done regularly once a year for the last seven years, and the following have been the results obtained. The delivery before the scraping was commenced was 317 gallons per minute, and after the first scraping it was 454 gallons per minute, being an increase of 43 per cent. on the previous delivery; and this increase was raised in successive years by the subsequent

annual scrapings to 78, 97, 108, 111, 116, and 115 per cent. of the original supply before the first scraping. The delivery gradually falls off again in each year up to the time of the next scraping, but this falling off becomes less each year, the amount just before the scraping in the last four years having been respectively 33, 49, 56, and 57 per cent. over the original delivery. From the uniformity of the results obtained in the two last years, it may be considered that the interior of the pipe has been now brought to an ordinary clean condition at each scraping; and when pipes are broken immediately after being scraped the original cast surface is everywhere visible. It is now found that the delivery is reduced from 681 to 499 gallons per minute by the incrustation formed in a single year, being a loss of 27 per cent. in the delivery. The several deliveries have been measured accurately by taking the times of filling a reservoir of known capacity, two similar reservoirs being filled alternately to receive the supply from the main.

Increased Delivery obtained by Scraping.

Year.	Total Delivery, gallons per minute.		Increase over original delivery of 317 gallons per minute.	
	Before Scraping.	After Scraping.	Before Scraping.	After Scraping.
	Gallons.	Gallons.	Per cent.	Per cent.
1866	317	454	0	43
1867	—	564	—	78
1868	—	624	—	97
1869	423	659	33	108
1870	471	668	49	111
1871	496	684	56	116
1872	499	681	57	115

The application of the scraper has been extended in the last three years to the 8 and 7 inch service mains of the town; and to meet the case of these smaller sizes of pipe, the simpler form of

scraper shown in Figs. 9 to 12, Plates 74 and 75, has been arranged, so as to occupy less space. A single spiral spring M is here made to serve the purpose of the previous spiral spring and flat spring for each scraping knife, by hanging the knife levers P obliquely, so that the motion is partly backward and partly inward from the single centre N. The whole scraper is shortened also, for the purpose of allowing its passage round the sharp curves in the service mains; and this scraper passes freely round a right-angled bend of 30 feet radius, made up of a series of straight lengths of pipe of about 4 feet each.

Mr. T. S. Weeks exhibited the successive scrapers employed for cleaning the water mains, including the original scraper first constructed, as well as the improved forms used subsequently, together with the cup employed for clearing out stones; and also a specimen of unscraped pipe, showing the extent of the incrustation that accumulated inside the pipe previous to its removal by the scraper.

Mr. Froude—in the absence of the author of the paper, Mr. Little, the Engineer of the Torquay Water Works—desired to supplement it by a few remarks, based on his personal experience of this subject, with which he had from the beginning been familiar, as the working out of the idea and the general management of the operations had been entrusted to him by the Local Board of Health. He wished to say that he had had, almost throughout, the skilled co-operation of Mr. Thomas Box, acting for Messrs. Easton and Co. who undertook the execution of the various mechanical arrangements which the work involved, and by whom indeed the Torquay water supply had been originally planned and carried into effect. He wished also to mention that the success with which the scraping operations had been carried out was very largely due to

the energetic and persevering exertions of Mr. Weeks, the Water Bailiff, throughout the whole of the work; even the very serious difficulty which arose from the stones encountered in the pipes, and which no skill could have mastered without the help of unlimited patience, did not discourage him, and Mr. Weeks had entered into the working of the plan with intelligence as well as perseverance.

One point of interest was the original determination of the fact that the obstruction to the flow of the water was due to the incrustation of oxide of iron within the pipes, although the diminution of the diameter was certainly trivial. The old opinion of hydraulic engineers had been that the mere roughness of the pipe would not cause such an amount of obstruction as was experienced; it was held that part of the water would become entangled in the interstices of the rough surface, which would thus be smoothed over, and the rest of the water would thereby be slipping along upon water instead of upon the rough surface of the pipe. That view had been entertained by Mr. Appold, who also thought the obstruction must be caused by accumulation of air. Without entering fully into the characteristic differences between the nature and operation of the obstruction caused,—first by internal roughness of pipe, secondly by the presence of internal solid obstacles, and thirdly by the presence of air within the pipe,—it appeared almost certain, with reference to these causes of obstruction, that the first would generally be uniformly distributed throughout the length of the pipe, since it would depend on the nature of the pipes themselves, and would therefore presumably be the same throughout. The second would probably be more or less localised. And the third would inevitably be localised at those particular parts of the pipe, and those only, where the features of the ground traversed offered facilities for the lodgment of air,—namely the descending sides of tolerably steep alternations of hill and hollow across which the line of pipes was laid: and especially those which occurred at comparatively high levels, where the absolute pressure of the water was small, since it was well known that wherever the pressure was very great, any air which was present must become rapidly absorbed by the water; so that, as regarded this particular

cause of obstruction, there would be no difficulty in deciding where to look for it, if at all. Again, it was obvious that if at any given intervals throughout the length of the pipe a series of open stand-pipes were carried up vertically from it to a sufficient elevation, and the level at which the water stood in each were gauged, then if the resistance to the flow were uniformly distributed, the levels of the successive gauge points would constitute a regularly graduated descent or gradient: this "hydraulic gradient" would in fact be uniform from inlet to outlet; while on the other hand, if definite local obstructions existed anywhere, whether caused by solid obstacles or by the presence of air, the hydraulic gradient would become irregular, exhibiting an abrupt descent at each obstruction, an excess of "head" becoming absorbed at each by the flow of the water past it. It had accordingly occurred to him that if, while the water was flowing steadily, its pressure were accurately gauged at sufficiently frequent intervals along the line of pipe, the heights of the equivalent columns of water might be calculated and laid down as ordinates, plotted from the pipe level on the section; and the tops of these ordinates would then constitute the resulting hydraulic gradient. If this gradient were irregular, the presence of air or of other internal obstructions would be indicated according to the locations and characters of the irregularities; but if the gradient were uniform, it would follow that the resistance offered by the pipe was uniform also; and if this resistance were greater than that due to the diameter of the pipes (allowing for the thickness of the incrustation), it would follow that the roughness alone was answerable for the excess of the resistance. He had therefore prepared a pressure gauge, in which the pressure was conveyed to a delicately mounted steelyard by an unpacked solid plunger of 1-5th square inch area; the fit of the plunger in its cylinder was at once easy and exact, so that it was in effect frictionless and water-tight even under 500 feet of head, and, even including the steelyard friction, would, if treated carefully, indicate up to that pressure within a foot of the true amount. He had also arranged a series of cocks at which to screw the pressure gauge on at

intervals along the course of the main, the method of drilling and tapping in being so contrived as to avoid any loss of water; and when the gauging had been completed, it was found that the hydraulic gradient was in effect quite uniform from end to end of the pipe: except that in one place, where a small local irregularity was met with, it turned out that there had been an error of about 2 feet in the levels of the original survey, which the hydraulic gradient not only gave the means of detecting, but indicated with exactness. It having thus been satisfactorily determined that the diminished flow through the pipe was owing to a uniformly distributed obstruction, and was therefore presumably due to the internal rough oxidation, Mr. Appold hit upon the very bold idea of forcing an effective scraper along the pipe by the pressure of the water behind it. The experiment was first tried upon a descending length of about $\frac{3}{4}$ mile of pipe, which was selected as suitable for the purpose. Before passing the scraper through, the established pressure was carefully gauged at each end of the length of pipe selected, and the hydraulic gradient accurately worked out, the actual descent of the pipe in the distance being carefully levelled so as to ensure minute exactness. The hydraulic gradient or consumption of head in the distance proved to be just 21 feet, or 28 feet per mile, forming in fact part of the uniform hydraulic gradient of the line. After the scraper had passed and the flow had been re-established, the pressures were again gauged and the hydraulic gradient again calculated, with the striking result that the consumption of head in the distance was only 1-3rd, or 7 feet instead of 21, giving a hydraulic gradient of only $9\frac{1}{3}$ feet per mile. This improvement if carried out over the whole length of pipe would have been equivalent to increasing the total delivery in the ratio of $\sqrt{3}$ to 1, or 1·73 to 1, giving therefore 73 per cent. increase in the total delivery, which would thus have been brought up to 87 per cent. of that due to clean pipes; and though the length scraped was so short, it had the effect of improving the total delivery by more than 1 per cent. On the strength of this promising result, which was so interestingly tested by the pressure gauge, the order was given for scraping the whole pipe.

Fortunately it was not then understood that the magnitude of this initial gain was partly due to a defect in the scraper, namely that from want of vigour in its cutting action it smeared as much as it scraped, and thus, by temporarily smoothing the interior, produced an effect which, though it was for the time more striking, was also of short continuance. In fact the result of this first experimental scraping was very nearly as good as was attained on the whole line after three or four years' scraping with greatly improved scrapers, the delivery after each scraping being always considerably more than that given by the previous year's scraping: though within a few weeks after the scraping a very sensible amount of the gain had vanished. The reason of this deterioration was not at first ascertained; the explanation however proved to be that the scraper not only cut off the projecting nodules but also filled up the hollows with the stuff scraped off, thus smearing the whole surface smooth and making it much easier for the water to pass; but after a few days the erosive action of the water would again have washed some of this loose matter out of the hollows, and the rate of flow would thereby be reduced. Experiments he had made with regard to the resistance encountered by different surfaces in passing through water fully bore out this conclusion, the difference in the resistance being very great for only slight differences in the roughness of the surfaces; for instance a thin plane when moved lengthways through the water, if covered with ordinary unbleached calico, met with twice the resistance that it did if simply varnished. On the whole, the delivery had improved year by year, and was now considerably in excess of that which the ordinary formula gave for clean pipes.

In the first scraper, as exhibited to the meeting, the ends of the flat springs were seen to be bent outwards so as themselves to form the scraping knives, the intention being that these springs should be made strong enough to do the scraping; but that principle was abandoned, because the springs, if stiff enough for this, were too stiff to yield readily enough on encountering any rigid obstacle. From 60 to 70 lbs. pressure upon each scraping knife was required to keep it to its work; but with this there was a risk that the hook-like spring end, if it happened to catch against the sharp edge of a

joint in the pipe, might hold fast like an anchor, and become bent or broken by the propelling force, which often was as much as 1200 or 1400 lbs. In the improved form of scraper now used, each of the scraping knives could yield backwards longitudinally, but if necessary without any inward movement, the two motions being entirely independent of each other; and it would always thus yield on meeting any solid obstacle that offered a resistance of more than 80 or 100 lbs. In fact when, as in the first scraper, the spring which dragged the scraping knife along the pipe was also that which pressed it outwards against the surface of the pipe, it was ill placed for being compressed by the dragging action of any solid obstacle which the knife might meet; for the friction which the propelling force created between the surface of the knife and the obstacle tended to hinder the knife from sliding off the obstacle, and might indeed be so great as to prevent its sliding at all: while if, as in the improved scraper, the knife could yield longitudinally when the obstacle was such as could not be sheared off, the force acted directly in the line of the motion and there was no induced friction. For the smaller pipes however it was necessary to adopt the simpler form of scraper, shown in Plate 75 and in the specimen exhibited, in which the backward movement of the scraping knives on encountering an obstacle was unavoidably combined with the inward movement withdrawing them from the surface of the pipe; the compound reacting force was given by a forward pushing spring alone, and the movement of the knife when yielding backwards was guided inwards by a pair of obliquely placed radius-rods or links; and this arrangement he understood had on the whole acted satisfactorily. One point to be noticed in regard to the improved scraper (Plate 73) was the use of springs in a very high state of compression for pressing the scraping knives outwards against the sides of the pipe and for holding them forwards to their work; these springs were very strongly compressed in putting the scraper together, their expansion being limited by suitable stops, and consequently their force did not become sensibly greater when slightly further compressed in passing any obstruction.

With reference to the stones found in the pipe, it was worth mentioning that their removal was not necessary on account of their impeding the delivery, as it was well known that a short contraction in a pipe produced very little diminution in the flow through it, and the presence of the whole number found probably did not consume altogether more than 15 or 20 feet of head of water. But although the stones were not answerable for any sensible loss in the delivery, they not only could not be removed by the scraping knives, but they interfered very seriously with the action of the scraper by clogging and breaking the springs and frequently jamming the scraper altogether. The stone-collecting cup was therefore necessarily employed, and as it had to pass through the pipe while still unscraped, and might have to pass over bad joints and other obstructions, it was necessary to have the outer edge bevilled backwards, as shown in the drawing and the cup exhibited; and this rendered it incapable of picking up small stones. The edge was therefore made strong, so that it might be capable of crushing any stone which was small enough to have become jammed into a joint, while it would push medium-sized stones in front of it and would scoop up the larger ones; and this arrangement seemed to have been successful in all particulars. The cup was taken out and cleared at intervals of two miles along the pipe, and on many occasions it was quite full, besides having a heap of stones in front of it.

Mr. W. Husband thought there could be no doubt that by the passage of the scraper any abrupt projections at the joints of the pipes or elsewhere would be smoothed down into inclined planes, by being plastered over with the deposit of the loose stuff scraped off; but as this would gradually wash out afterwards, the projections would then become again abrupt, and would impair the increased flow of water which at first resulted from the scraping.

Mr. G. D. Hughes enquired what was the cost of the scraping operation.

Mr. Froude replied that the cost of the first scraping had amounted to as much as £1000, because it had been necessary

in the first instance to lay a number of door-pipes in the main, at which to insert the scraper; these were laid at every two miles, and thus formed a considerable part of the cost of the first scraping.

Mr. T. S. WEEKS said the total cost of the first two years' operations, including the alterations of the pipes and the construction of the successive scraping implements, had been about £1200; but at the present time the cost of scraping the whole length of the pipe did not exceed £10 or £12 each time, provided the implements did not get damaged in any way during the operation. On one occasion when it had happened that the position of the scraper in the pipe had been entirely lost, it was recovered by the plan suggested by Mr. Box of drilling holes along the pipe, each time dividing the length into two equal parts, and noting the flow of water from them; and it was evident that by boring ten holes in the two miles interval between any two successive door-pipes, the determination of the scraper's position was brought within a distance of about 9 feet, or a single length of pipe. It took thirteen or fourteen hours to find out the scraper by this means, but still it was the only way.

Mr. JEREMIAH HEAD enquired whether, as the ingenious and very simple apparatus described in the paper had been found to be of such use in the Torquay Water Works, its employment had been extended to other works. He thought there must be other water works elsewhere, in which the flow would be improved by occasionally passing a scraper along the mains.

Mr. E. EASTON mentioned that last year he had constructed a similar apparatus for scraping the pipes of the Barrow-in-Furness Water Works, where trouble had also been experienced from the same cause, namely the very great purity of the water.

The CHAIRMAN enquired whether it was a fact that the formation of this kind of obstruction in water mains was due to the water being extremely pure; and whether it was only met with in pipes that were not coated with any composition to protect the metal from the action of the water.

Mr. E. Easton believed it was the case that the incrustation of oxide in water mains arose from extreme purity of the water; but wherever Dr. Angus Smith's composition had been used, which consisted of a mixture of tar and linseed oil, no difficulty had ever been experienced that he was aware of. He had seen the working of the scraper in the main of the Torquay Water Works, and the stuff scraped off was taken out of the pipes at the doors provided for the purpose at every two miles distance along the entire length of the main; the addition of these doors accounted for the high cost of the scraping in the first instance. He recollected that, when the original scraper designed by Mr. Appold was first tried on the ¾ mile length near Bovey Tracey, the quantity of stuff that came out was astonishing, nearly a cartload of it being scraped from that length of pipe. Before the scraping was tried, it had been a question whether it would not be necessary to lay down another main for the entire distance at a cost of £30,000; but the present very ingenious arrangement, for which the greatest possible credit was due to Mr. Froude and Mr. Weeks, had saved that great outlay, at a cost of only £1200 for the first scraping.

The Chairman said he had been present at one of the scrapings of the Torquay main, and it was very curious to listen to the scraper at work; a strange subterranean rumbling was heard along the roadway under which the main was laid, yet there was nothing to be seen; the sound was quite distinct enough to enable the motion of the scraper to be followed and its position to be determined without any difficulty. When one of the side doors of the main was opened in advance of the scraper, the water first came out the colour of chocolate, and gradually got thicker and thicker until it became a stiff mud; the amount of this stuff that was discharged was so great that it would hardly be believed by any one who had not seen it. The abnormal increase in the delivery or passage of water that was observed for a short time immediately after each scraping must arise, he thought, from the temporary equalising of the surface of the pipes, rather than from the removal by the scraper of any local obstructions; for a mere local obstruction was of very little importance in

diminishing the flow, and waterworks engineers did not scruple to put a comparatively small screw-cock in a large main, knowing that the flow was thereby diminished only to an extent that would be equivalent to adding a few feet more to the length of the main.

He proposed a vote of thanks, which was passed, to Mr. Little for his paper and the collection of specimens exhibited, and to Mr. Froude and Mr. Weeks for the information they had kindly supplied.

The following votes of thanks were then moved by the Chairman, and passed :—

To the Committee of the Royal Cornwall Polytechnic Society, for their kind invitation and cordial reception of the Institution at the Cornwall Meeting;

To the Honorary Local Secretaries, Mr. J. Henry Collins, F.G.S., and Mr. Henry T. Ferguson, for the very excellent arrangements they had so kindly made for the Meeting;

To the Proprietors of the different Mines and Works visited in the Excursions, for their kindness in affording the opportunity of seeing their Works, and for their hospitable reception of the Members on the occasion; and

To the Railway Company, for the special facilities and privileges granted for the Excursions.

The Chairman announced that the Museum of the Royal Geological Society of Cornwall, adjoining St. John's Hall, was open to the Members of the Institution, through the kind invitation of the President, Mr. Warington W. Smyth, F.R.S.

The Chairman further announced that the Annual Meeting of the Institution in next summer was intended to be held in South Wales.

The Meeting then terminated.

In the afternoon the Members visited the Tin Smelting Works of Messrs. Bolitho in Penzance, where the whole of the process of smelting tin from the ore was seen. The tin ore (peroxide of tin) supplied from the mines under the name of "black tin" is charged by hand shovels into reverberatory furnaces, each charge consisting of 30 cwts. of black tin, previously mixed with 2½ cwts. of "culm," which is the "small" of the South Wales anthracite coal and is free from sulphur. The charge remains in the furnace about six hours, the firing being moderate at first, and afterwards more intense; the charge is only stirred once, about half an hour before tapping, more frequent stirring being avoided because the draught of the furnace carries off a quantity of the finest particles of the tin ore, and deposits it in the chimney and on the roofs, whence it is only partially recovered by collecting the rain water in tanks. The liquid metallic tin is run off from the furnace through the tap hole into a large cast-iron pan, from which it is ladled into moulds, the slag being skimmed off. The "coarse metal," as it is then called, containing about 95 per cent. of pure tin, is next refined by the two processes of "liquation" and "boiling." In the former, the blocks of coarse metal from the smelting furnace are piled up in a refining furnace, and the tin is melted out at as low a temperature as possible, and run off into a basin, called the boiling kettle; as pure tin melts at a lower temperature than the impure metal, that which runs into the kettle is purer than the blocks of coarse metal supplied into the refining furnace. The kettle is heated by a slow fire to keep the metal just melted; a bundle of sticks of green wood in an iron cradle is then plunged into it to the bottom, and the steam given off from the wood rises up through the mass of melted metal, and any impurities that may be present are carried with it to the surface, where they form a scum; the violence with which the steam escapes gives the metal the appearance of boiling. About 10 tons of metal at a time are boiled in the kettle, and the boiling is continued as long as any scum continues to rise to the surface; the damper the wood, the quicker is the boiling completed, the time occupied being from three to four hours. Samples are taken from

each charge to show the quality of the metal, which is then ladled into smaller moulds to form the slabs for sale. The dross remaining in the refining furnace is afterwards subjected to a much higher heat in another furnace, to melt out all the tin possible; and this then undergoes liquation in the refining furnace with a fresh charge of coarse metal, together with all the scum that is skimmed off the boiling kettle. The slag remaining in the smelting furnace after tapping is raked out at the back, and solidifies in large masses, which are broken up first by hand hammers and then by crushing rolls; the coarser portions are returned to the smelting furnace with a fresh charge of ore, and the finer after having been washed and jigged are stamped by ordinary tin stamps; the slimes from the stamps are allowed to settle in "strips" or tyes, and are washed on a hand "frame," the metal recovered being sent to the refining furnace, while the waste is thrown away. The tin ore or "black tin" from the Cornish mines yields on an average 66 per cent. of metal or "white tin," 1 ton of metal being obtained from $1\frac{1}{2}$ ton of ore. Stream tin ore is richer, whether Cornish or Australian, and yields up to 72 and even 75 per cent. of metallic tin. The Members were entertained at the works by Mr. Thomas S. Bolitho at a luncheon of steaks cooked upon the hot slabs of freshly run tin standing in the moulds to cool.

Excursions were then made by the Members in two parties, by special conveyances, to visit Botallack and Boscaswell Downs Tin and Copper Mines near St. Just, and the Longships Lighthouse near the Land's End.

At Botallack Mine, where the Members were received by the Purser, Mr. S. Harvey James, the Diagonal Shaft extending under the sea at an inclination of $32\frac{1}{2}°$ to the horizon (Plate 34) was descended in a safety break-carriage lowered by the winding engine with wire rope, as far as to the 190 fathom level, the water being in the bottom of the mine up to that level, from which a small quantity of tinstone of poor quality is at present being raised. The water from the 190 fathom level is hauled in a barrel by the winding engine up to

the 180 fathom level, along which it runs back to Button shaft sunk to that level, and is raised by the pumping engine in Crowns shaft, by means of flat rods taken along a higher level from one shaft to the other. The 165 fathom level is the one that has been driven furthest out to sea on this lode, called Crowns lode; but it has now been abandoned, the end being very poor. The most promising part of the mine at present is at Wheal Cock in the northern portion, where a lode containing good yellow copper ore and good tinstuff has been discovered, and is being opened upon; a timber framework 95 feet high is erected at the top of the shaft to carry the head gear for winding the stuff, in order to develope this part of the mine rapidly. The dressing operations are carried on in accordance with the description given at the meeting in the paper on Ore Dressing Machinery; in the part of the mine visited there are altogether sixty-four heads of ordinary stamps, and fifteen circular buddles all convex, and a large circular frame. The slimes are dressed by fifteen of Zennor's machines, each of which consists of a circular revolving table, 17 feet diameter, having a slightly conical surface rising about 6 inches to the centre; the centre spindle on which the table revolves is canted at such an inclination as to raise the edge of the table on one side just level with the centre. The slimes are delivered upon the table at the centre, but only over the quadrant immediately preceding the lowest point of the edge; and during the slow rotation of the table, which is at the rate of one revolution in three minutes, a continuous gentle stream of pure water is delivered upon it, which washes off the waste over the edge at the lower side, while the richer tinstuff deposited upon the table and thus cleaned from the waste is carried round to the higher side, where a stronger stream of pure water washes it off into a separate receptacle. The small proportion of tinstone that contains mundic is calcined in a small reverberatory furnace stirred by hand, the quantity not being sufficient to require the employment of a self-acting calciner.

The Members were also invited by Capt. Richard Williams to visit Boscaswell Downs Mine, and witness the working of the

semiportable winding engines employed there, as described in the paper read at the meeting.

The Longships Lighthouse, visited through the special invitation of the Resident Engineer to the Trinity Board, Mr. Michael Beazeley, stands on a rock of killas at a distance of $1\frac{1}{3}$ mile from the Land's End, and has been built from the designs of Mr. James N. Douglass, Chief Engineer to the Trinity Board, to supersede an old lighthouse erected on a pinnacle of the same rock by private enterprise in 1795. The new tower is built entirely of granite, and is 106 feet high, the total height including the lantern being 132 feet. The solid basement of the structure, containing fifteen courses of 2 feet thickness, is constructed of very fine-grained granite from Dinan in Brittany; the upper portion is of granite from the Lamorna quarries near Penzance, chiefly in $1\frac{1}{2}$ foot courses; and the thickness of the walls diminishes gradually from $7\frac{3}{4}$ feet at the bottom to $2\frac{1}{4}$ feet at the top. The outline of the tower is an elliptical curve, the diameter being 35 feet at the base, and 17 feet at the top below the gallery course, which spreads out to 21 feet diameter. Advantage was taken of the form of the rock to leave a solid cone, round which the first ten courses are built as a casing; as these do not extend round the entire circle, the end stones of each course are notched into the solid rock, which is accurately benched to receive the several courses. In the first entire course each stone is bolted to the top of the cone of rock by strong bolts of Muntz metal, and each stone of the first five entire courses is bolted to those below in the same manner. The remainder of the courses are secured to those immediately below by a circular dovetailed band and groove, by which they are so bound together as to become virtually one solid mass; the individual stones in each course are likewise dovetailed together, so that none of them can be detached without disturbing the whole course. The floors are "through" stones, united by a centre stone dovetailed into all the others, thus binding the whole structure together at the level of each floor, and avoiding all outward thrust upon the tower from vaulted voussoirs. The whole work is entirely

set in Portland cement, which was carefully worked into all the joints by means of thin iron "swords" until every crevice was filled. There are seven rooms in the lighthouse, and a large fresh-water tank in the basement beneath the first room; the windows are protected by strong gunmetal shutters and frames, fixed flush with the outside of the tower, and the entrance is closed by thick gunmetal doors. The framing of the lantern is constructed of steel, and is carried upon a cast-iron pedestal; it was first fitted with the catoptric apparatus from the old tower, which will be replaced by a first order dioptric light apparatus; the elevation of the light gives it a sea range of 16 miles distance. A fog bell is suspended from a bracket on the gallery, and is rung by machinery during thick weather. For landing the stones and supplies a wharf was constructed on the rock, provided with a powerful crane, the winch and jib of which were lowered down into a protecting chamber when not in use; and on the top of the rock was placed a steam winch for raising the stones by means of a jib to the top of the work, where the setting was done by a second shorter jib, without interfering with the lifting jib. These two jibs were fitted to a central wrought-iron mast, which was gradually raised by hydraulic jacks as the work advanced; the mast being turned perfectly true in the lathe for its whole length, and accurately adjusted in the centre of the tower, formed a true centre for a trammel by which the stones were set. All the stones above the basement were dressed at the Trinity wharf in Penzance, and each successive floor and room was completely fitted together there, and then taken apart and conveyed to the rock, 13 miles distance, in barges towed by a steam tug. In consequence of the very exposed position of the rock, the work could only be proceeded with in calm weather, and frequently an interval of many days passed, in which no landing upon the rock could be effected. The operation of preparing the rock having been commenced in 1869, the foundation stone of the tower was set on 7th August 1871; and on 21st August 1872, just over a year afterwards, the last stone at the top of the tower was set. The lantern was then fixed, the old tower taken down, and the pinnacle of rock on which

it had stood was carefully removed by blasting, with continually diminishing charges of powder so as not to injure the solid rock near the base of the new tower. The total cost of the lighthouse when completed will be £34,000. The number of stones in the tower is 965, measuring 22,900 cubic feet and weighing 1,700 tons; and the total number of hours occupied in landing and setting the stones was 640, the entire tower being thus placed on the rock in 64 working days of 10 hours each, without the occurrence of any accident during the whole progress of the work.

In the evening the Members and their friends dined together in Penzance, in celebration of the first Cornwall Meeting of the Institution.

On Thursday, 31st July, an Excursion was made by the Members by special train from Penzance to visit Dolcoath and Carn Brea Tin and Copper Mines, near Camborne; and at Hayle, Messrs. Harvey's Engineering Works, and Wheal Lucy Tin Mine.

At Dolcoath the Members were received by Capt. Josiah Thomas, who showed sections of the mine and described the nature and extent of the underground operations. The present working was commenced in 1799, the mine having stood idle for thirteen years after the previous working, during which it had been drained entirely by a Newcomen engine, the bottom being only 150 fathoms below the adit; but on the working being resumed a Watt pumping engine with 60 inch cylinder and 7 feet stroke was erected to drain the mine, afterwards a second with 70 inch cylinder and 7½ feet stroke, and in 1869 a modern Cornish engine with 85 inch cylinder and 9 feet stroke. The mine being situated exactly upon the junction of the granite and killas, the upper portion of the principal lode, known as Dolcoath Main Lode, is in the killas, in which it has

but little underlie; it passes into the granite at a depth of about 150 fathoms, and then underlies south about 18 inches per fathom. Down to about 200 fathoms depth the lode was very rich in copper, of which £3,000,000 worth was raised in the earlier part of the present working from a length of about two thirds of a mile on the run of the lodes between the boundaries; it was principally yellow copper ore in the rich part of the lode, but very little copper ore is now being raised; only a small quantity of tin was met with in the killas. In the next 30 fathoms the lode was poor, and was in a transition state, containing a little tin and copper mixed, but not enough of either to pay for working; below that depth however it became richer in tin, averaging 2 per cent. of black tin, and containing also a little yellow copper ore. The present deepest level is 314 fathoms below adit, or about 350 fathoms below surface, and the lode is there very rich in tin, averaging as much as 8 per cent. of black tin; the lode in the bottom of the level is 12 feet wide, and worth £120 per fathom, (that is 1 fathom forwards, 1 fathom high, and the width of the lode,) equivalent therefore to £60 per cubic fathom. The highest temperature experienced in the deepest levels has been 85° Fahr. The shaft that is sunk to the bottom of the mine is used both for pumping and for winding; it is sunk vertically till it meets the lode at 160 fathoms depth from surface, and then follows the underlie of the lode to the bottom; the pump rods are turned from the vertical into the inclined direction by a radius bob at the angle; the plunger lifts are each about 240 feet height. At this shaft the stuff is raised in a kibble, about $2\frac{1}{2}$ feet diameter and $4\frac{1}{2}$ feet high and containing about a ton of stone, a steel wire rope 1 inch diameter being used; there are no guides in the shaft, and in the lower inclined portion the kibble and rope rub on the timber lining of the shaft. The time occupied in drawing the kibble to surface from the depth of 350 fathoms is about 8 minutes, giving a mean speed in the shaft of about 3 miles an hour; at the two deepest shafts about 10 tons per hour are raised, which is as fast as the stuff can be got in the workings; from the deepest level nearly the whole of the stuff broken is being

N 2

sent to surface, the lode being there remarkably rich. During the last twenty or thirty years skips working between guides have been gradually introduced; and the other winding shaft at Dolcoath is provided with guides and skip. The levels are driven 12 fathoms apart, to prove the lode, which where soft is stoped overhand, that is, in the roof or back of the levels ; but if hard, the stoping is done underhand, in the bottom of the levels. The dressing floors are very extensive, comprising as many as 232 heads of ordinary stamps, worked by three engines; there are 30 buddles, all convex, which with other portions of the dressing floors are roofed in, and lighted with gas for continuing the dressing operations by night. The calcining is done by three of Brunton's horizontal calciners, and the consumption is about 1 ton of coal to 12 tons of "whits," which yield about 3 tons of black tin. About 1200 persons are employed on the mine, of whom 500 are engaged underground; the quantity of material raised annually is about 70,000 tons.

At Carn Brea Mine the Members were received by Capt. William Teague. The two principal lodes at this mine are producing both copper and tin, but a larger quantity of the former than of the latter at the present time, though the tin is becoming more abundant as greater depth is attained. The deepest level is 266 fathoms below surface, and is in granite, the junction of the killas and granite occurring here at about 110 fathoms depth; there is about a mile length on the run of the lodes between the boundaries. Three pumping, five winding, and three stamping engines are at work on the mine; the latest of the stamping engines, erected by Messrs. Harvey in 1871, is one of the most recent examples of a good rotary Cornish engine, having a cylinder of 34 inches diameter and 9 feet stroke, working with 55 lbs. steam cut off at 1-12th of the stroke; the usual vacuum is about 12 lbs. per square inch. This engine is at present driving 80 heads of ordinary stamps, being capable of driving 20 more also. Steam is supplied to it by three Cornish boilers, each 30 feet long and $5\frac{3}{4}$ feet diameter with $3\frac{1}{4}$ feet flue, which are fired with fine slack, the firing being done from two to four times per hour; the whole of

the ashes are preserved, and mixed with the slack for burning over again. There are altogether 208 heads of stamps at work, and the dressing floors, which have recently been newly laid out upon the most modern plans, contain 23 convex and 40 concave buddles. Two of Oxland and Hocking's calciners are employed, the cylinders being 32 feet long, placed at a slope of 1 in 24, and making one revolution in eight minutes. A pair of crushing rolls and a set of hand jigging machines dress the copper ore raised at the mine. A man-engine is employed for taking the miners to and from their work in a shaft sunk vertically a depth of 200 fathoms below surface; the rod has a stroke of 12 feet, and is worked at a speed of four double strokes per minute, by a 26 inch cylinder engine with 8 feet stroke making four strokes to one in the shaft; this man-engine was seen at work and partly descended by the Members. The oldest of the pumping engines is a vertical combined-cylinder engine on Sims' plan, erected in 1841, having cylinders of 90 and 50 inches diameter and 9 feet stroke, the high-pressure cylinder being placed on the top of the low-pressure cylinder on the same piston rod; it is probably the last specimen of this class of engine still continuing at work in Cornwall, and is about to be replaced shortly by a modern Cornish pumping engine. The Members were entertained at luncheon at Carn Brea by Capt. Teague, who also presented each of them with specimens of the tinstone raised at Carn Brea mine, and of the dressed "black tin" and the metallic tin obtained from it.

At Hayle the Members were conducted through the Engineering Works of Messrs. Harvey and Co. by Mr. William Husband; and large Cornish pumping and winding engines were seen in course of construction, one having a cylinder of 80 inches diameter and 10 feet stroke. Two of the large pumping engines for draining Haerlem Lake were made at these works, with annular cylinders of 144 inches diameter and 10 feet stroke; and marine engines have been made up to 60 inch cylinders, the different shops being furnished with machinery suitable for turning out the heaviest descriptions of work. An iron screw steamer of 650 tons burden, for navigating

shallow waters, was seen in course of construction, 172 feet long and 27 feet beam, to be fitted with compound engines having cylinders 33 and 18 inches diameter and 1 ft. 9 ins. stroke.

At Wheal Lucy Tin Mine the Members were received by Capt. William Harris, who showed the working of Husband's pneumatic stamps described at the meeting, of which a pair of heads have been successfully working there for fifteen months, driven from the rotary double-acting pumping engine.

On the return to Penzance in the evening by special train, the Members visited St. Michael's Mount and Castle, through the kind invitation of Sir John St. Aubyn, Bart., M.P.; and they were conducted by the Steward, Mr. Joseph Thomas, round the base of the rocks, to see the interesting illustration afforded there of the junction of the granite and killas, the south-west portion of the Mount being composed of granite, and the north-east of killas. The granite, which forms the greater part of the hill, has the appearance of having been forced up through the killas, into which several small veins of granite penetrate; and the junction of the two formations is distinctly seen on the rocks at the base of the Mount, where also at low tide veins of tin and copper ore are discernible. The Members returned by water to Penzance.

On Friday, 1st August, an Excursion was made by the Members by special train to the West of England China-Clay Company's Works at Drinnick Mill, near St. Austell, where they were received by the Managing Director, Mr. Edward Stocker. The clay is worked in extensive open cuttings, the largest of which is 100 feet deep; and streams of water being directed down the sloping face of the workings upon the lines of the richest clay deposit wash the clay down, together with the sand and mica, which are here mixed with it

in the proportion of about 8 tons of sand and mica per ton of china-clay. The several streams of water meeting at the bottom of the cutting are well stirred with hand shovels, to facilitate the separation of the sand from the clay; and the whole of the liquid mixture is run into a large reservoir at some distance, where much of the mica becomes deposited. The remaining liquid, containing nearly all the clay, is then pumped up into a series of long settling channels, called "micas," about $3\frac{1}{2}$ feet wide and 9 inches deep and from 100 to 200 feet long and upwards; these have a very slight fall of 1 inch in about 40 feet, and are interrupted by dams or weirs at about every 20 feet, so as to give the stream of clay solution a succession of checks, whereby the heavier particles of mica are deposited. From the lower end of these channels the clay solution passes off through a fine grating, to strain out as much as possible of the remaining mica; and in order to prevent the grating from becoming clogged with particles of mica and clay, it is subjected to the constant blows of a light hammer worked by a small waterwheel, giving about 30 blows per minute; the slight jarring action produced is sufficient to prevent the stuff from settling upon the grating. The clay solution is then conducted into large tanks or "pans," about 40 feet long, 50 feet wide, and 6 feet deep, where the clay now freed from mica is allowed to settle, and the water is gradually run off as the thickness of the deposit increases. When sufficiently solidified, the deposited clay is removed in cubical blocks, which are dried either in the open air or in kilns, according to the weather; in wet seasons, air drying cannot be resorted to, as the clay would be washed away again. The drying kilns are 120 feet long, each capable of drying 4000 tons of clay per year, and each charge requires about 24 hours to dry at the hot end of the kilns. About 23,000 tons of clay per year are being sent out of these works, which are at present in a very early stage of their development, and are being greatly extended by opening additional workings at several different points. The sand separated from the clay is used for making excellent firebricks, and mixed with a certain proportion of coarse clay it also makes good and durable building bricks of white colour; the bricks are hand-

pressed, the manufacture being at present only on a small scale, and are then dried on drying floors with flues running beneath them, and are afterwards burnt in kilns. A quantity of china-stone is also quarried, and sent away to be used for glazing pottery. Some parts of the works are kept constantly going, by night as well as by day; and the total yield of the various products from these works at present amounts to 30,000 tons per annum. The Members were entertained at luncheon at the works by the Company.

The train then proceeded to Saltash, where, by the special invitation of the Chief Engineer of the South Devon, Cornwall, and West Cornwall Railways, Mr. Peter J. Margary, the Members were conducted over the Royal Albert Bridge, and were enabled to ascend into the tubes, under the guidance of the District Engineer, Mr. William Wright.

The Royal Albert Bridge at Saltash carries the Cornwall Railway over the River Tamar, which divides Cornwall and Devon. The river is required to be kept navigable for large vessels of war, and the bridge crosses it with two spans of 433 feet clear opening, and 100 feet clear height from high water. The bridge is of peculiar construction and was designed by Mr. Brunel, assisted by Mr. Brereton, to meet the special requirements of the case; the ironwork was executed by Messrs. Hudson and Male.

Each span is formed of an arched tube, with the ends tied together by suspension chains in a corresponding inverted curve, and the roadway suspended below for a single line of railway. The tubes are of wrought iron, of $\frac{1}{2}$ to $\frac{3}{4}$ inch thickness, of oval section 12 feet deep and $16\frac{3}{4}$ feet wide and having a sectional area of metal of 433 square inches; they are made with an internal stiffening ring at every 20 feet of the length, and longitudinal stiffening ribs. The curve of the tubes has a rise of 29 feet, and the chains have a drop of 27 feet, giving a total depth of truss of 56 feet centre to centre, amounting to about one eighth of the span. The chains are double, consisting altogether of four rows of fourteen and fifteen links alternately, each 7 inches by 1 inch section in the fourteen links, giving a total sectional area of 392 square inches.

They are connected to the tube by a series of vertical struts, strengthened by diagonal ties; and the transverse girders carrying the roadway are suspended from the chains. Each tube with roadway complete weighs about 1100 tons.

The ends of the tubes are flattened at the sides, with extra plates and struts inserted for the attachment of the ends of the chains; and the outer end of each tube rests upon four rows of $3\frac{1}{2}$ inch rollers, each 3 feet long, which move in roller boxes filled with oil and planed true at the bottom, to allow of the expansion and contraction from change of temperature. The greatest change observed was between the summer and winter of 1860, from 117° down to 20°, being a range of 97° of temperature, and the variation caused in the length of the tubes was $2\frac{3}{4}$ inches.

The outer ends of the tubes are carried on brick standards, built upon granite piers 29 feet by 19 feet, and the inner ends rest upon a cast-iron standard erected upon four octagonal cast-iron columns 10 feet diameter and 89 feet height, which are put together in 6 feet lengths, and stand upon a solid granite pier 34 feet diameter, built in the middle of the river, with its base 90 feet below high water. The erection of this centre pier in so great a depth of water was the greatest obstacle to be overcome in the whole structure, and specially showed the originality of Mr. Brunel. The depth of water, 64 feet at high water, precluded the use of a cofferdam; and a preliminary examination was made by Mr. Brereton by means of a wrought-iron tube 6 feet diameter, with which rock was found at 21 feet depth below the bed of the river, or 85 feet below high water.

A wrought-iron cylinder 37 feet diameter and 95 feet height was then sunk down to the rock in the required position, for the purpose of building the pier within it, pneumatic pressure being employed for keeping out the water while excavating and constructing the foundations; and in order materially to diminish the quantity of work that would have to be done under pneumatic pressure, the bottom of the cylinder was made with an internal cylindrical lining of 27 feet diameter and 20 feet height, thus leaving an annular chamber of 5 feet width all round between the lining and the cylinder. This

annular chamber was closed at top by an air-tight diaphragm, the work being performed within it under pneumatic pressure; and by this air pressure any water leaking into it from the outside was pressed into the central compartment of the cylinder, which was left open to the atmosphere and from which the water was pumped. With this arrangement the only work required to be executed under pneumatic pressure was an annular wall of masonry of 5 feet thickness and 37 feet diameter, during the construction of which the drainage was maintained by pumping from the central open compartment. On the completion of the annular foundation wall to the height of 20 feet, the pneumatic apparatus was removed and the central core built up to the same height, the leakage of water being found to be no more than the pumps could keep down; after which the building of the rest of the pier within the cylinder was completed in open air up to the top. In sinking the cylinder for the pier, it was loaded partly with cast-iron ballast, and partly with water by means of a water-tight lining carried down from the top of the cylinder to the top of the annular pneumatic chamber, leaving a central space of 10 feet diameter for access to the bottom of the cylinder; on completion of the foundations this lining was removed for building up the rest of the pier. The total weight of the cylinder and inner linings was about 360 tons.

The two arched tubes were erected complete with their chains and roadway on the bank of the river, and floated upon pontoons into their places one at a time at high water; the pontoons then sinking with the tide left the tubes resting upon the piers just above high-water level; from which they were raised by three hydraulic presses at each end up to the permanent level of 100 feet above high water. The floating of the tubes to their places was effected with complete success, each tube being accurately guided whilst floating by means of hawsers from five vessels moored in the river and four crabs on the shore, all the movements of which were regulated by signal flags from the floating tube.

The bridge when completed was tested by the passage of a pair of heavy engines with a long train, and the deflection produced was very minute. The approaches to the bridge are formed of seventeen

openings altogether, of from 70 to 90 feet span, crossed by wrought-iron girders. The bridge was erected in 1857; and twice since then, in 1861 and 1867, the outside has been scraped and repainted, the last time with two coats of Torbay paint; and once, in 1864, the inside of the tubes was scraped and tarred; the total area of painting is $7\frac{1}{4}$ acres. The condition of the whole structure as regards durability is apparently as good as when first erected.

The total weight, including the approaches, is 2600 tons of wrought iron, and 1200 tons of cast iron; and the total cost was £223,220, amounting to £102 per foot run for the total length of 2190 feet.

The Members then visited Keyham Steam Yard, Devonport, by kind permission of the Admiral Superintendent, Sir William King Hall; and were conducted by the Engineer-in-Chief, Mr. John Trickett, over the large foundries, forges and smithies, boiler shops, turning, fitting, and erecting shops, provided with all the appliances requisite for turning out the machinery of the largest vessels for the navy. The double-turret ship "Hecate," recently built, was visited, as well as other vessels in various stages of progress.

The Members proceeded to Plymouth, remaining there that night.

On Saturday, 2nd August, the Members visited Devonport Dockyard, by kind permission of the Admiral Superintendent, and saw the very extensive machinery employed in the preparation of hemp and the manufacture of ropes and cables of all sizes for the purposes of the navy; the largest cables are as much as 25 inches in circumference, and are made in lengths up to as much as 200 fathoms. The cable-testing arrangements and the

wood-working machinery were also seen; and the boat house containing a number of screw launches, with portable engines ready for application to any one of them.

A special steamer then conveyed the Members to H. M. S. "Cambridge" Training Ship lying in Hamoaze, through which, by kind permission of Commander the Hon. H. Holmes à Court, they were conducted by Captain Herbert, who showed the arrangements made for giving a course of instruction in practical gunnery to the officers and men of the Royal Navy.

The Plymouth Breakwater, and the new armour-plated Fort erected in its rear, were then visited, by kind permission of Major General Sir Charles Staveley; and the Excursion was extended to the mouth of the Yealm River, noted for its fine coast scenery, and to the Eddystone Lighthouse at 13 miles distance; and afterwards up the River Tamar to Saltash, for affording the Members a view of the Royal Albert Bridge from the water.

In returning from the Cornwall Meeting several of the Members availed themselves of Mr. Froude's kind invitation to visit the experimental works adjoining his residence at Chelston Cross, Torquay, where he showed the working of the machine used for shaping ship-models, as described in the paper at the meeting, and also the rest of the interesting and ingenious apparatus employed in carrying out the very extensive experiments upon the forms and resistances of ships.

BRACKET CHAIR.

Fig. 1. *Side Elevation.*

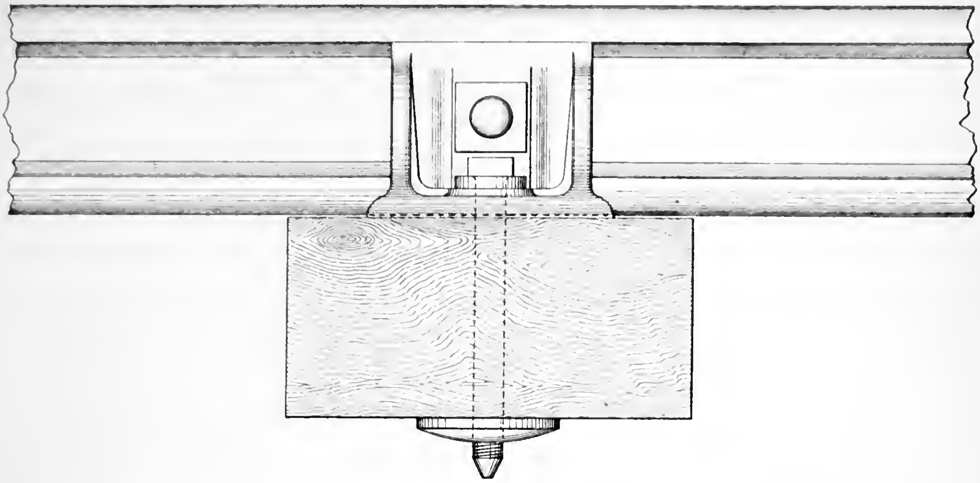


Fig. 2. *Transverse Section.*

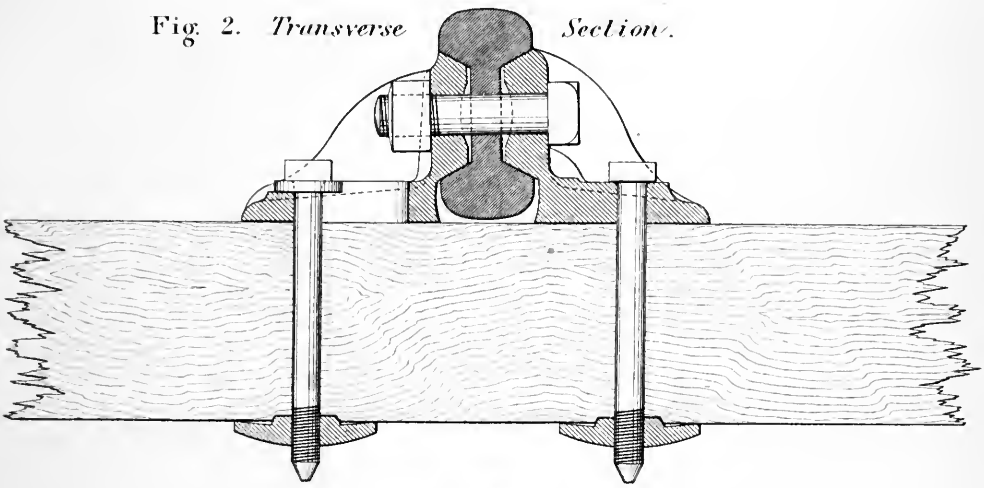
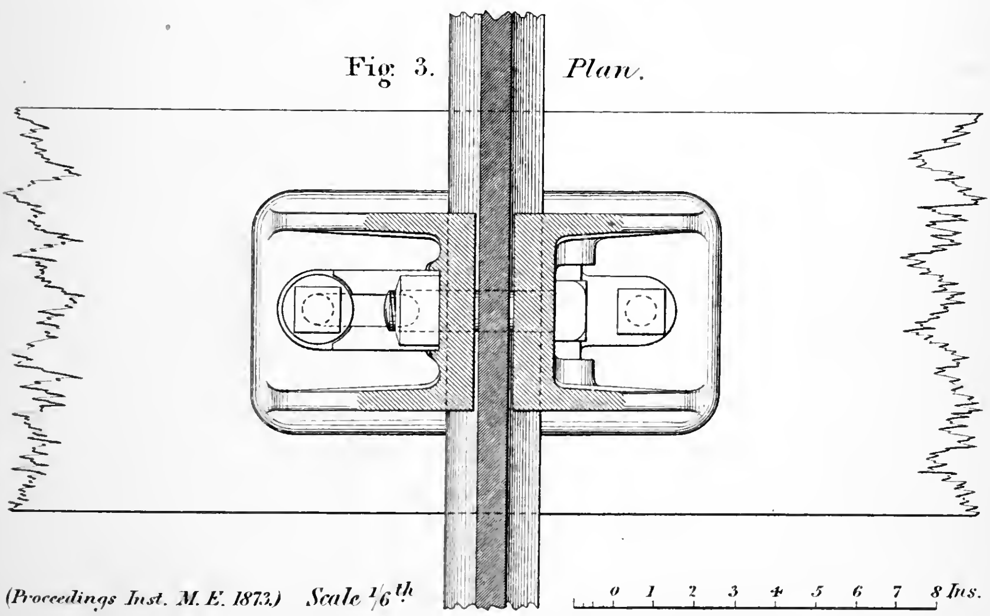


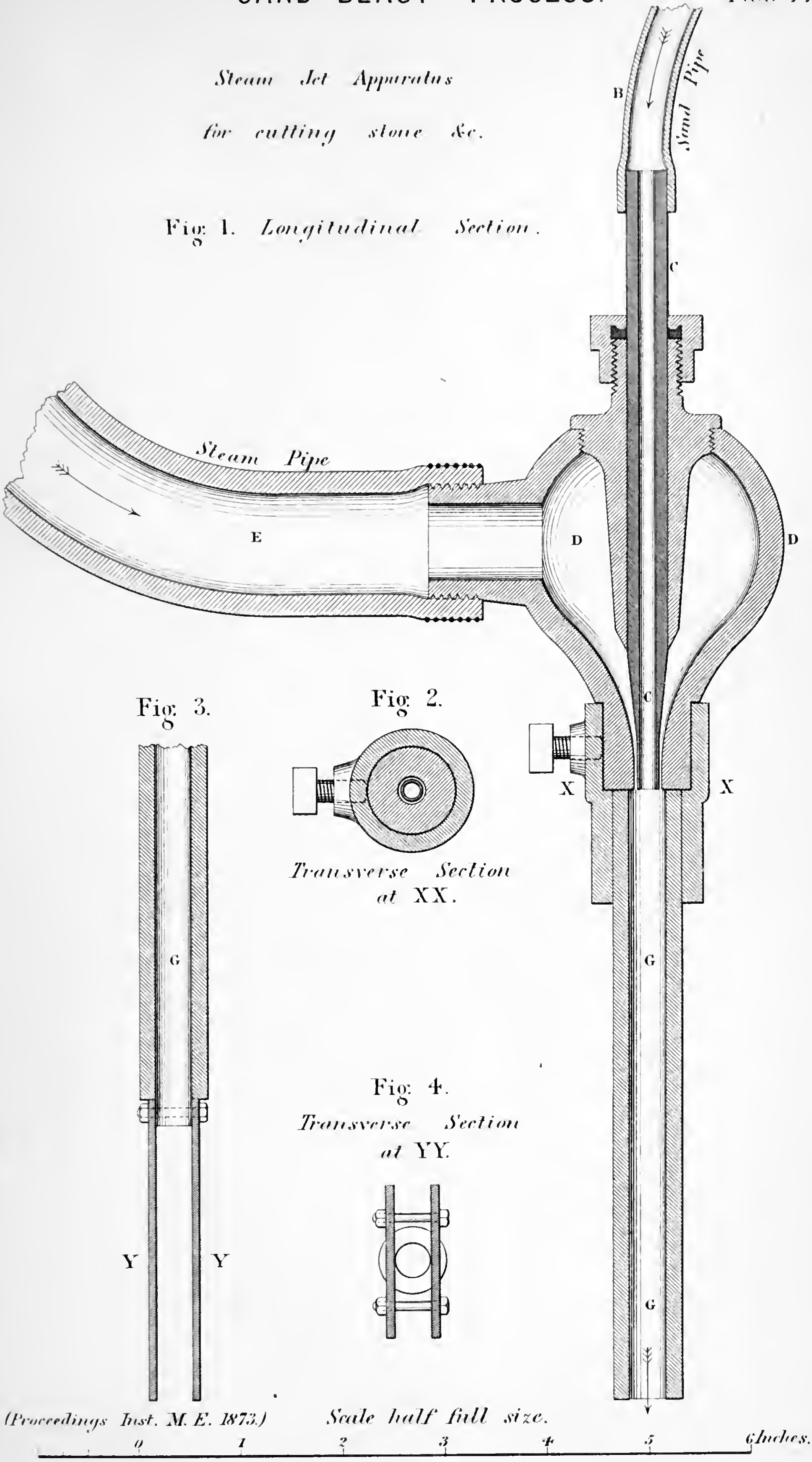
Fig. 3. *Plan.*



(Proceedings Inst. M. E. 1873.) *Scale 1/6th*

0 1 2 3 4 5 6 7 8 Ins.

Steam Jet Apparatus
for cutting stone &c.

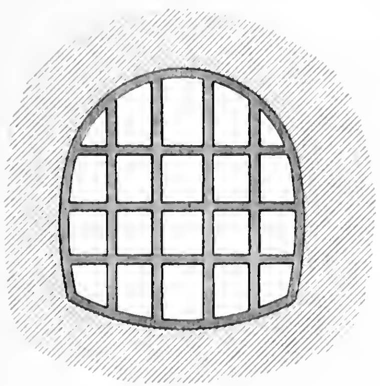


(Proceedings Inst. M. E. 1873.) *Scale half full size.*

SAND-BLAST PROCESS.

Mode of application for Cutting Grooves in Stone.

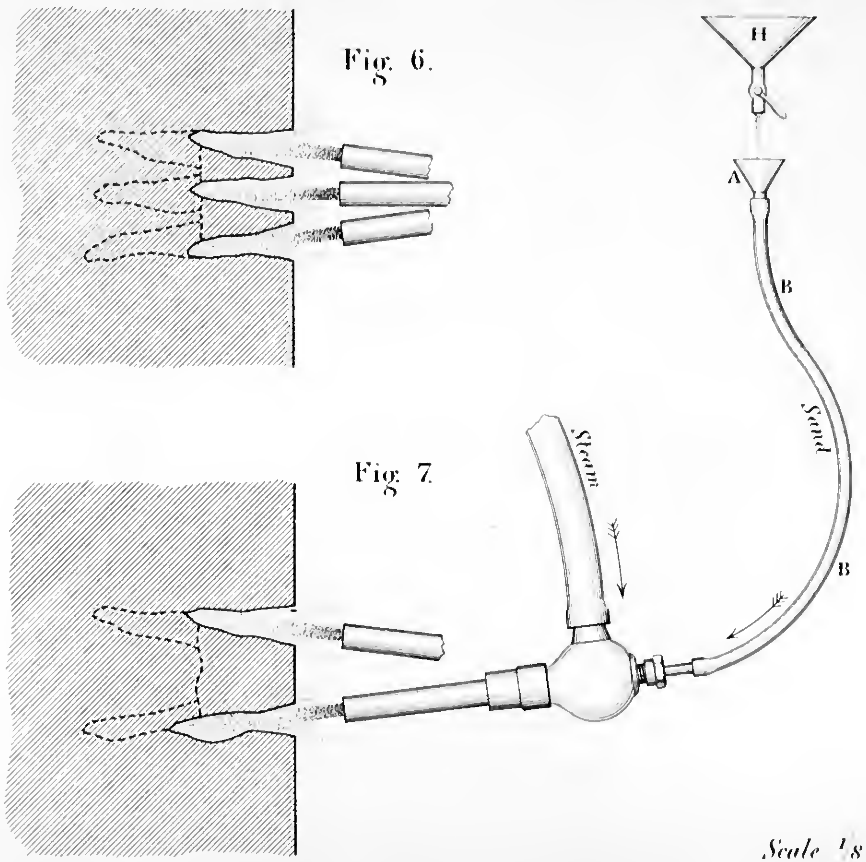
Fig: 5. *Tunnelling.*



Scale $^1/_{120}$ th

Fig. 6.

Fig: 7.



Scale $^1/_{8}$ th

Fig: 8. *Shaping a Round Baluster.*

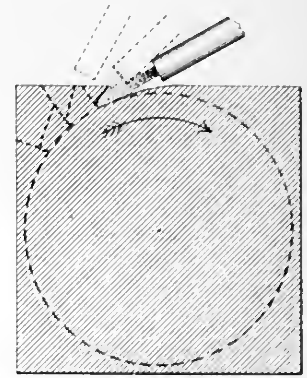
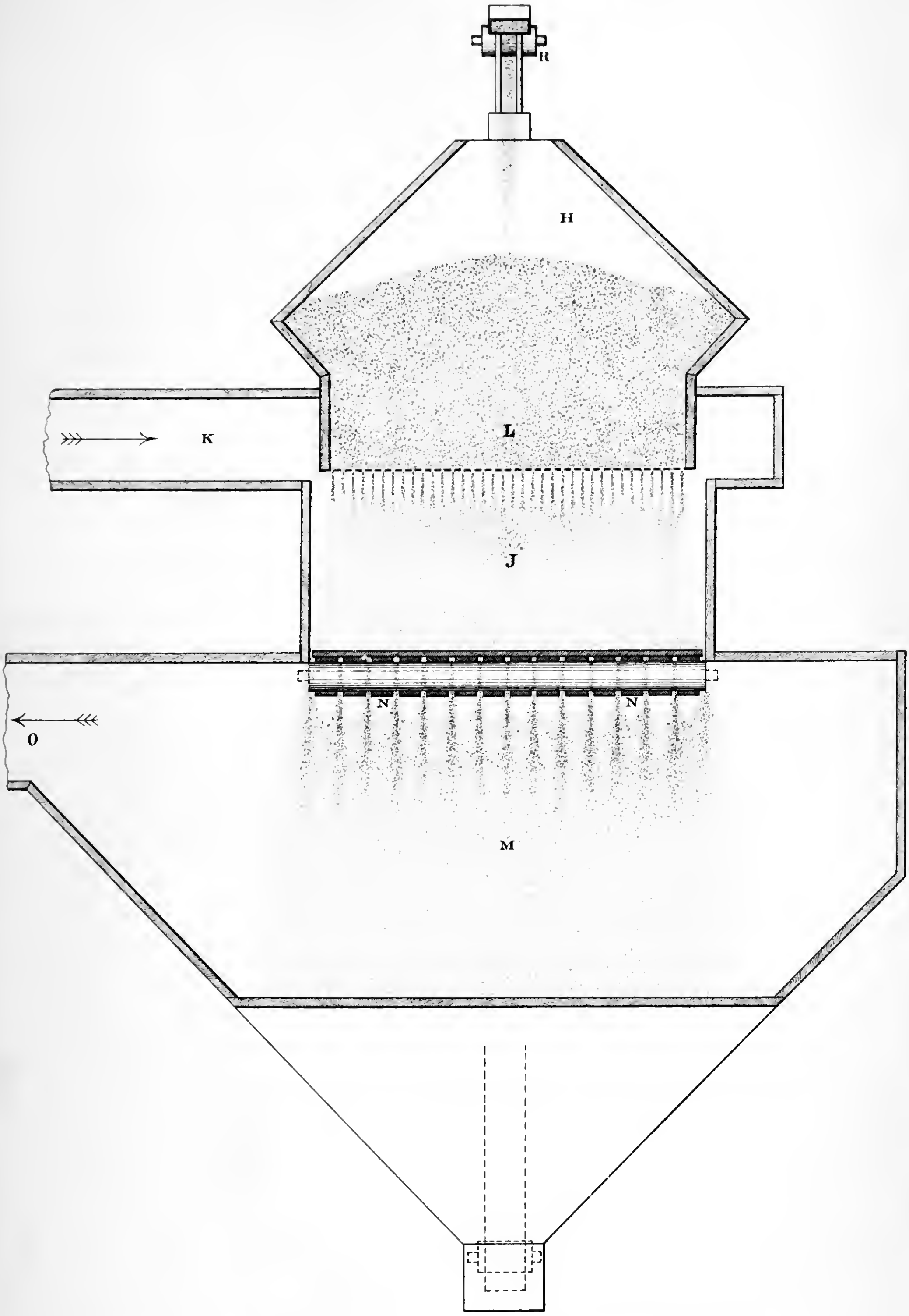


Plate 78.

SAND-BLAST PROCESS. *Plate 79.*

Apparatus for Grinding or Depolishing Glass.

Fig. 9. *Transverse Section.*



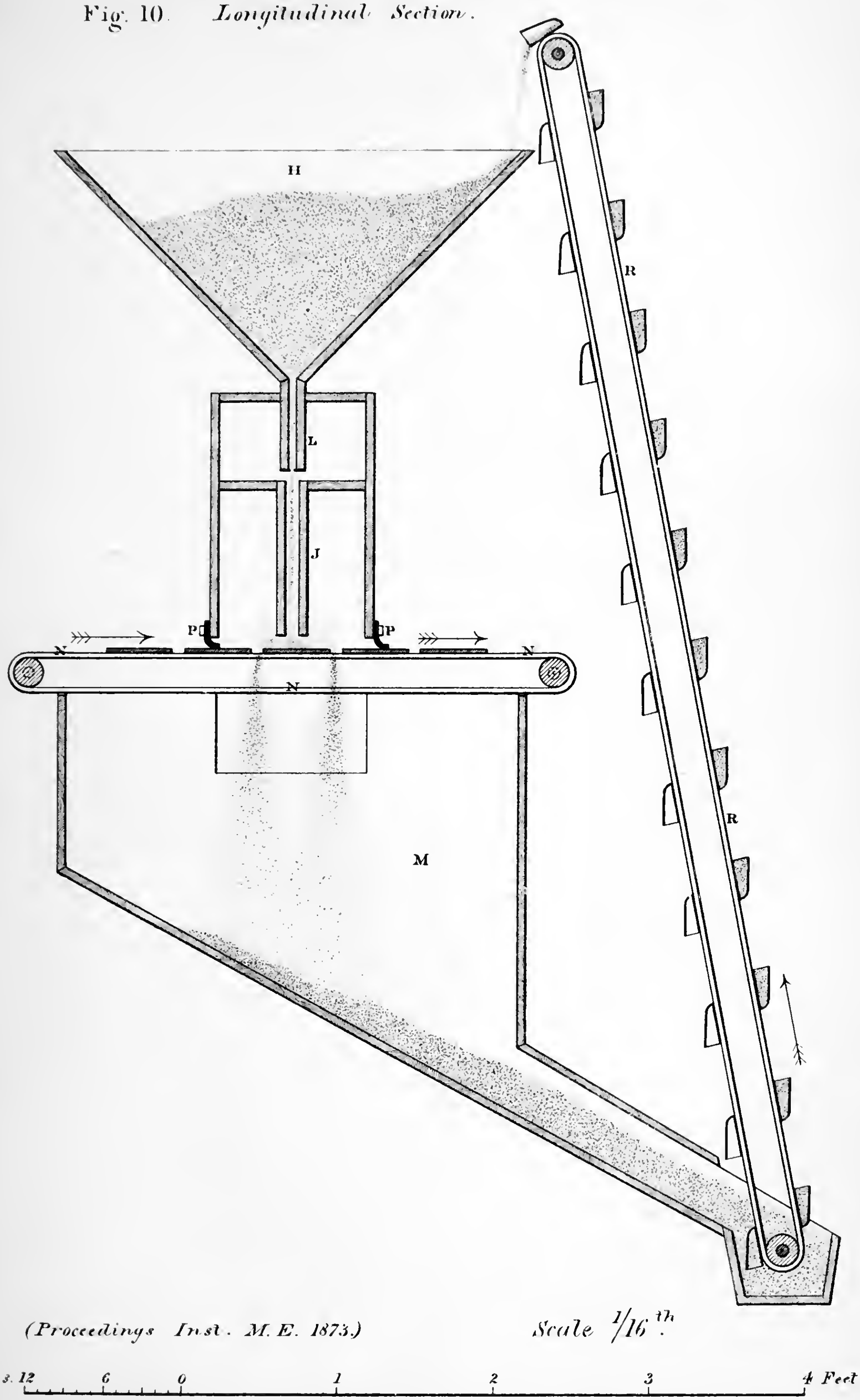
(Proceedings Inst. M. E. 1873.)

Scale 1/16th.

SAND-BLAST PROCESS. *Plate 80.*

Apparatus for Grinding or Depolishing Glass.

Fig. 10. *Longitudinal Section.*



(Proceedings Inst. M. E. 1873.) *Scale 1/16th.*

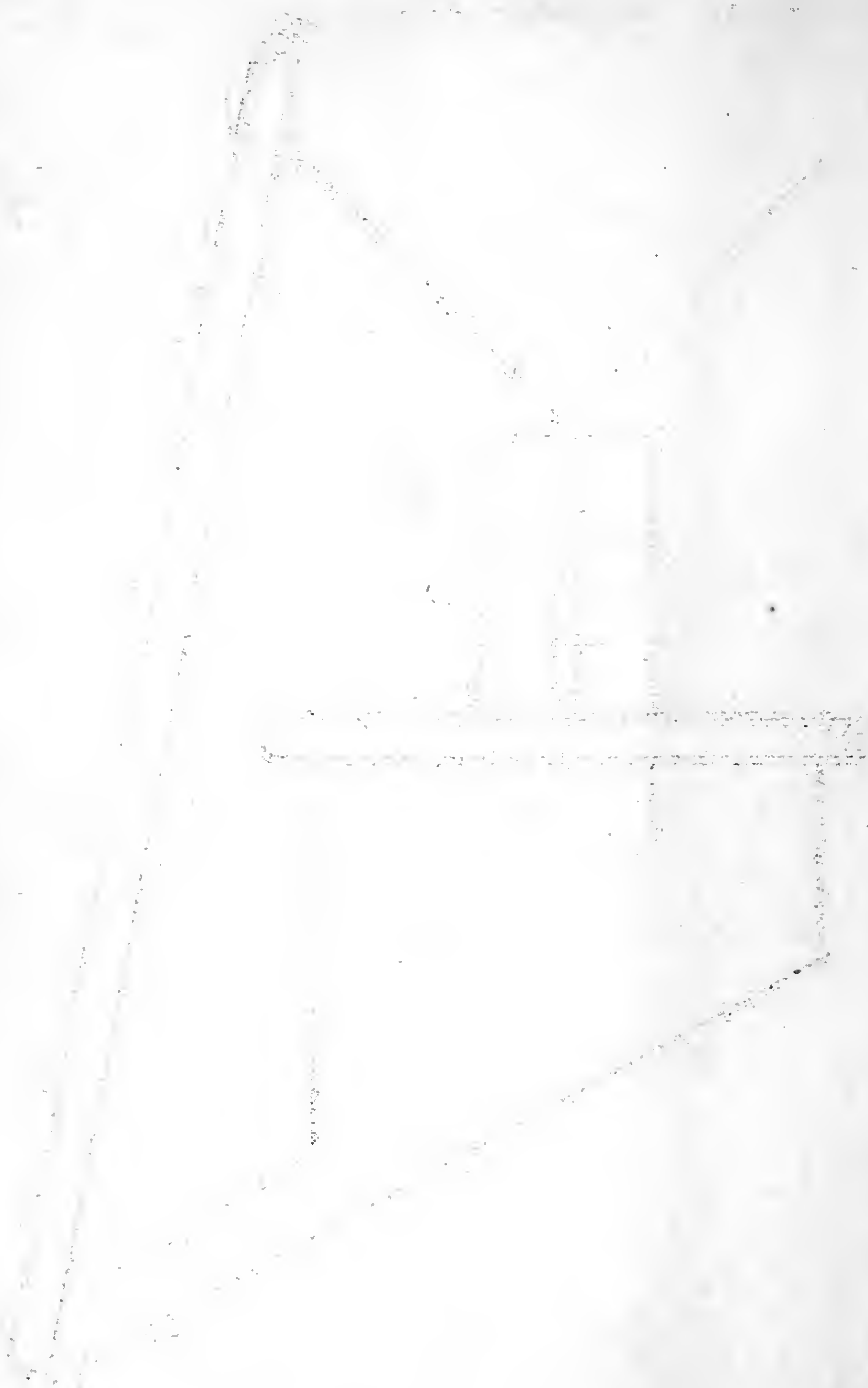


Fig. 1. *Elevation, when closed*

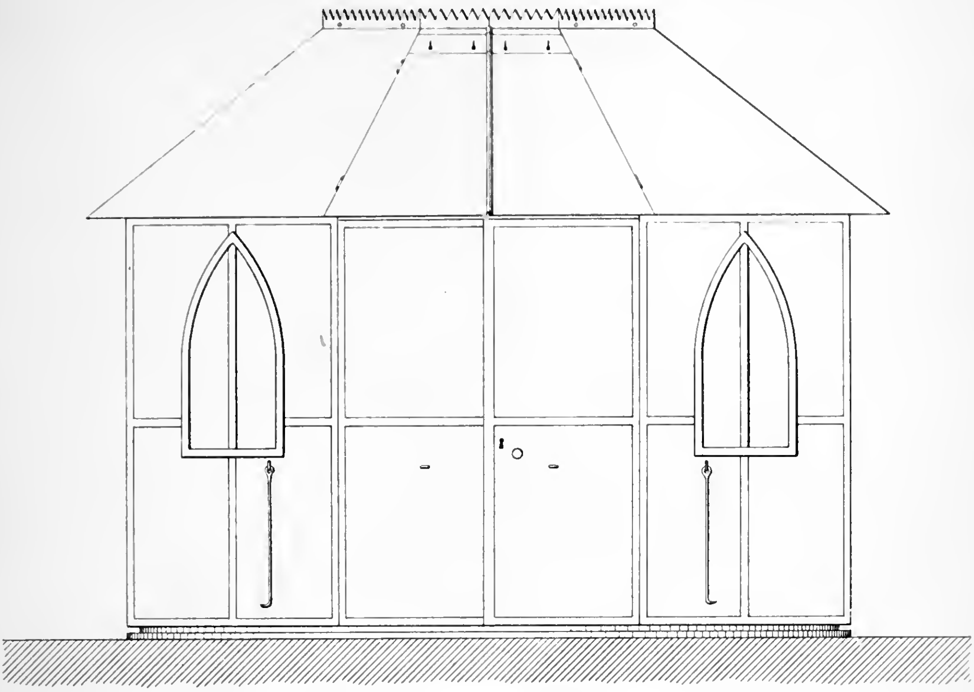
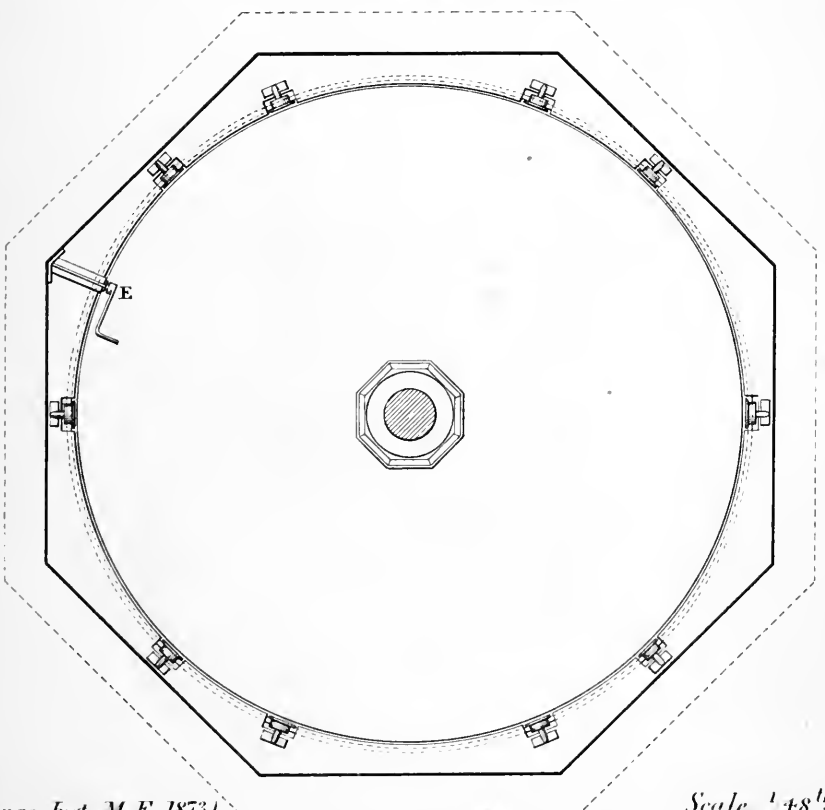


Fig. 2. *Sectional Plan.*



Scale 1/48th

0 3 6 9 12 Feet.

WROUGHT-IRON OBSERVATORY. *Plate 82.*

Fig. 3. *Elevation when open for use.*

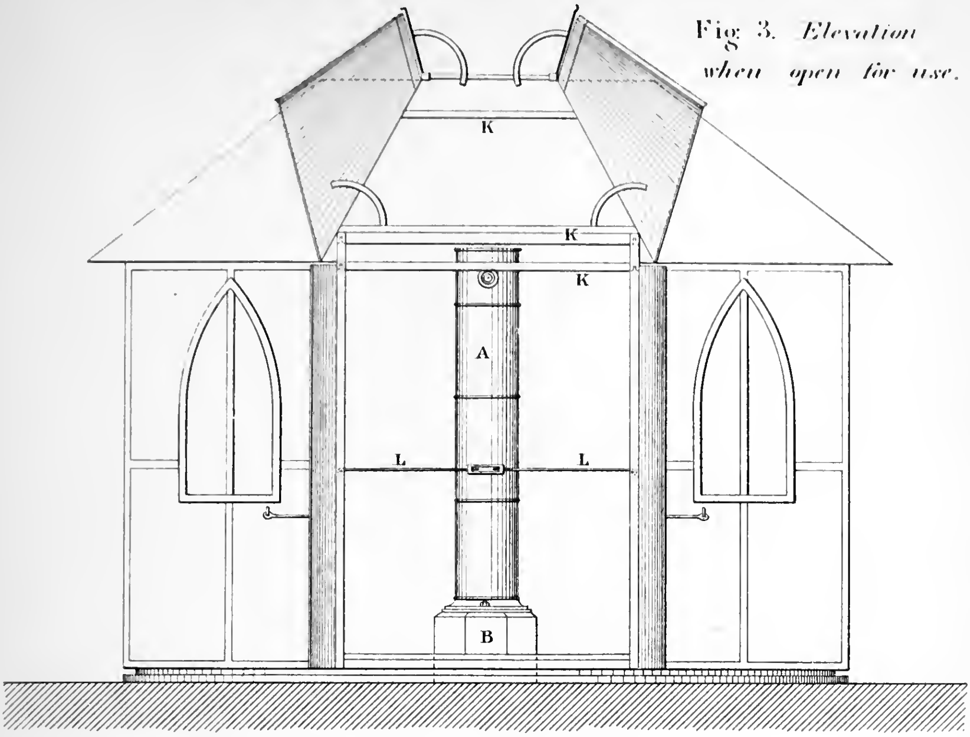
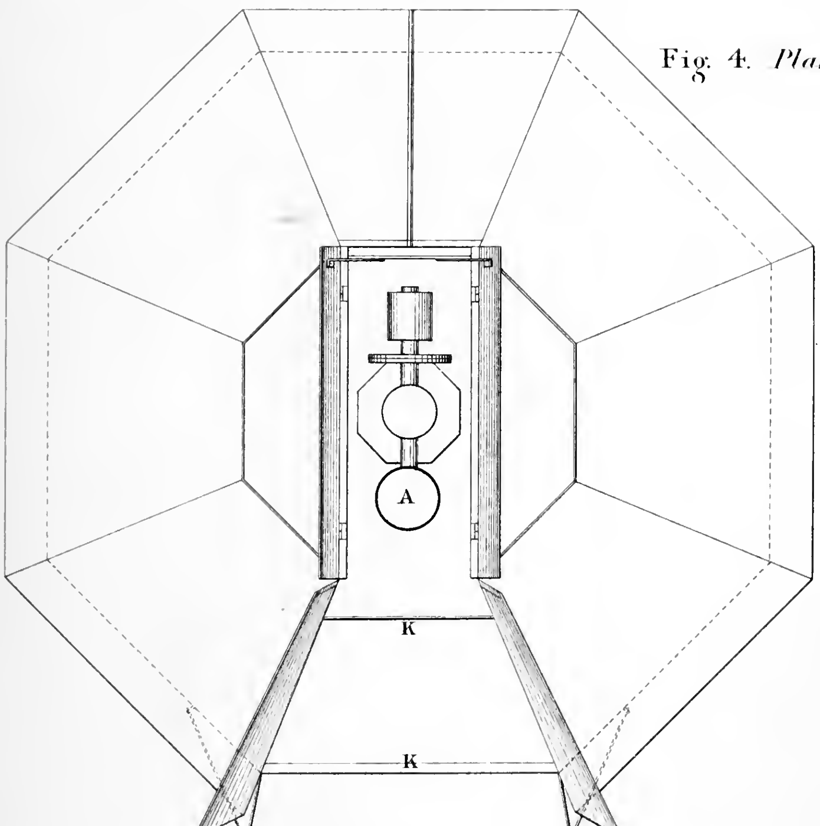


Fig. 4. *Plan.*

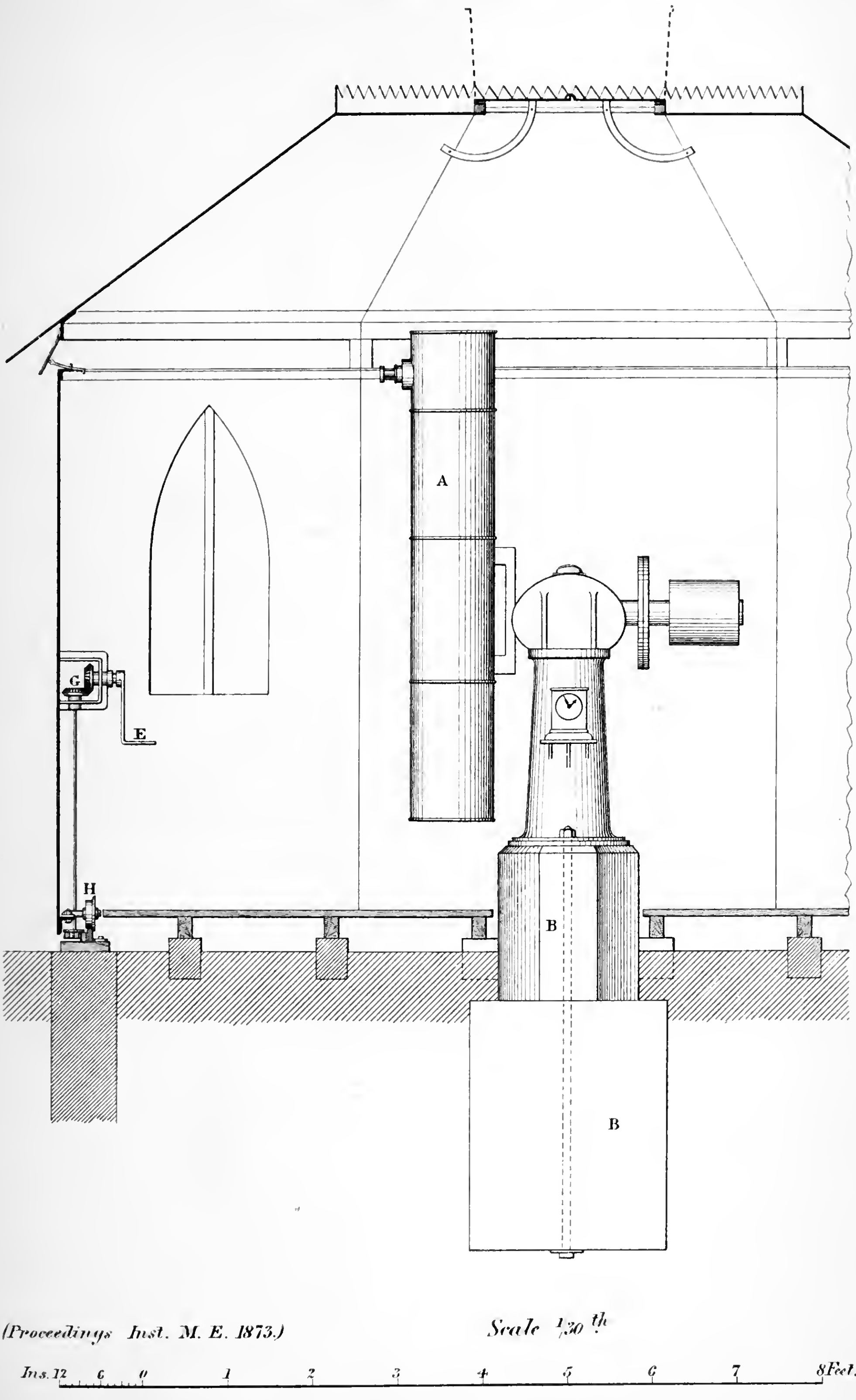


(Proceedings Inst. M. E. 1873.)

Scale 1/48th

0 3 6 9 12 Feet.

Fig. 5. *Vertical Section.*



Scale 1/30th

Fig. 6. *Top Roof Doors.*

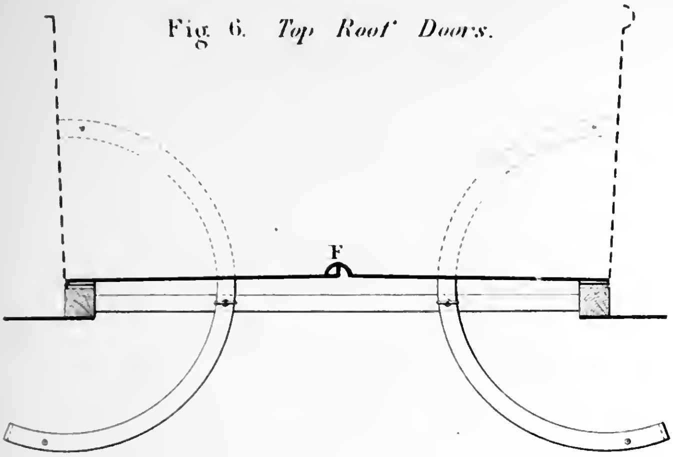
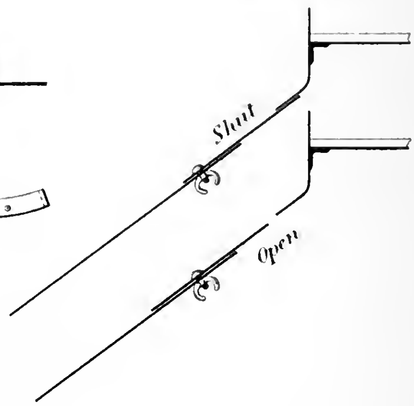


Fig. 7.

Cover Slide.



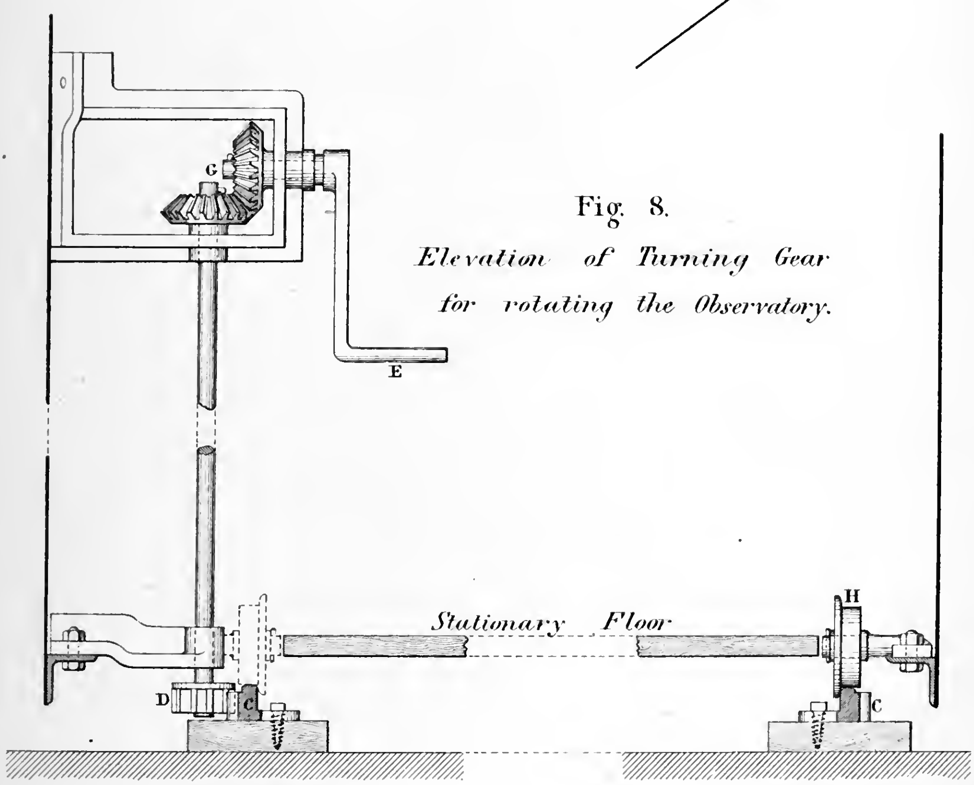


Fig. 8.

Elevation of Turning Gear for rotating the Observatory.

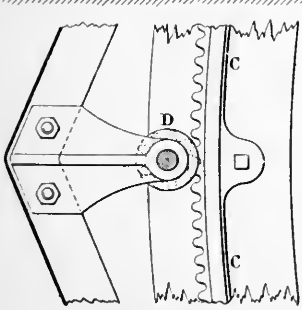
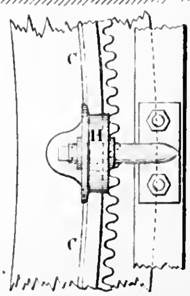
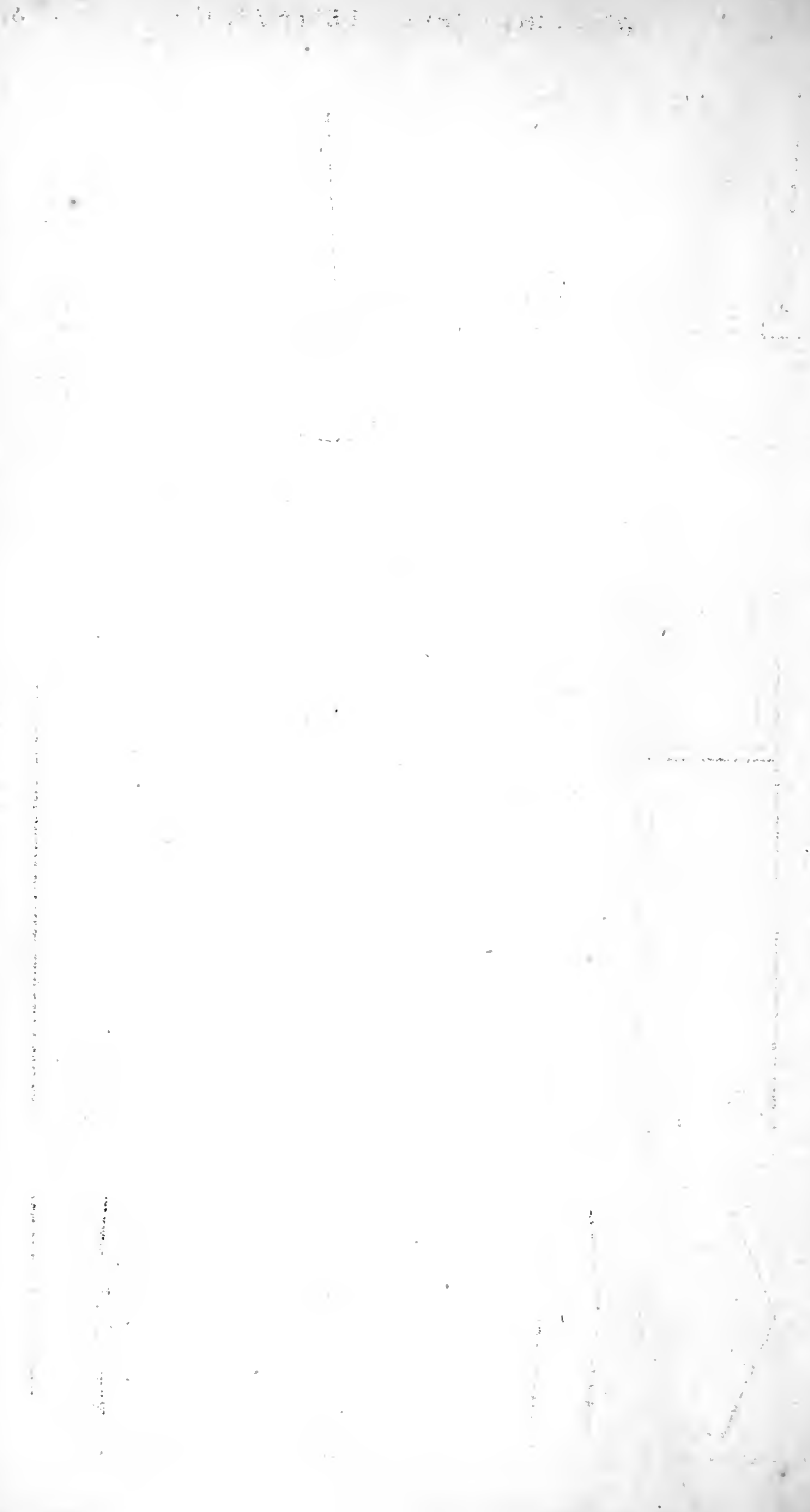


Fig. 9. *Plan.*



Scale 1/12 th.

10 5 0 10 *Inches.*



PROCEEDINGS.

30 OCTOBER, 1873.

The GENERAL MEETING of the Members was held in the Lecture Theatre of the Midland Institute, Birmingham, on Thursday, 30th October, 1873; C. WILLIAM SIEMENS, Esq., D.C.L., F.R.S., President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The PRESIDENT announced that the President, Vice-Presidents, and five Members of the Council in rotation, would go out of office in the ensuing year, according to the rules of the Institution; and that at the present meeting the Council and Officers were to be nominated for the election at the Anniversary Meeting in January next.

The following Members were nominated by the meeting for the election at the Anniversary Meeting:—

PRESIDENT.

FREDERICK J. BRAMWELL, F.R.S., . London.

VICE-PRESIDENTS.

(*Six of the number to be elected.*)

CHARLES EDWARDS AMOS, . . . London.
JOHN ANDERSON, LL.D., . . Woolwich.
I. LOWTHIAN BELL, ... Newcastle-on-Tyne.
CHARLES COCHRANE, . . . Dudley.
EDGAR GILKES, ... Middlesbrough.
THOMAS HAWKSLEY, . . . London.
JOHN HICK, M.P., ... Bolton.
SAMPSON LLOYD, ... Wednesbury.
WILLIAM MENELAUS, ... Dowlais.
JOHN NAPIER, ... Glasgow.
JOHN ROBINSON, ... Manchester.

COUNCIL.

(*Five of the number to be elected.*)

William Anderson,	London.
Joseph Armstrong,	Swindon.
Henry Bessemer,	London.
William Clay,	Birkenhead.
Edward A. Cowper,	London.
William Froude, F.R.S.,	Torquay.
George Harrison,	Birkenhead.
Jeremiah Head,	Middlesbrough.
William W. Hulse,	Manchester.
John McConnochie,	Cardiff.
Richard Taylor,	London.
Percy G. B. Westmacott,	Newcastle-on-Tyne.

The President announced that the Ballot Lists had been opened, and the following New Members were found to be duly elected:—

MEMBERS.

Henry Marc Brunel,	London.
Robert Burton Buckley,	Shahabad, Bengal.
Bryan Donkin, Jun.,	London.
Harry Jones Harman,	Brora.
Frederick Colthurst Kelson,	Cork.
Arthur Lucas,	London.
John Penn, Jun.,	London.
William Penn,	London.
Robert Robey, Jun.,	Lincoln.
Marshall Stonehouse,	Swansea.
Charles Dyke Taylor,	Devoran.

ASSOCIATES.

William Henry Barry,	London.
William George Freeman,	Penryn.

GRADUATES.

Robert Moss Collingham, ...	Lincoln.
Richard Joseph Caistor Dobson, ...	Rouen.
Alfred Simpson, ...	Hull.

Mr. A. Paget gave notice that at the ensuing Anniversary Meeting of the Institution in January he would propose, that, as the attendance at the last Spring Meeting in London was more than three times the former average attendance at the Meetings in Birmingham, the Council be requested to hold other future Meetings in London, in addition to the Spring Meetings, with a view to decide the question as to whether London is or is not a more convenient place for the Meetings of the Institution than Birmingham; and that, in order to give the Council power to do this, the Rules be altered by adding in paragraph 1 of section 5 the words "or London" after the word "Birmingham."

The following paper, communicated through Mr. William Wright, of Lostwithiel, was then read:—

DESCRIPTION OF THE BRACKET CHAIRS FOR SUSPENDING DOUBLE-HEADED RAILS ON THE WEST CORNWALL RAILWAY.

By Mr. JAMES D. SHERIFF, of Truro.

In the Chairs ordinarily used for Double-headed Rails the rail rests entirely upon the bottom, and in consequence of the bearing surface being small the bottom head of the rail becomes indented; and by the time the top head has been worn so far as to require the rail to be turned, the indentations of the bottom head are often found to be so considerable as to prevent the rail being used when turned. The special advantage intended to be obtained with the double-headed rail, namely the power of turning it and getting a second period of wear out of the lower head, is thus lost; and the double-headed rail has consequently been abandoned in several cases for the single-headed rail, which is an inferior form as regards distribution of material for strength, and also as regards durability wherever both heads of the double-headed rail can be used. The importance of preserving the double-headed rail from wear of the bottom head has led to the trial of several plans for suspending the rail in the chair by giving it a bearing only under the upper head, a moveable jaw being fitted into the chair for this purpose, in place of the wood key employed in the ordinary chairs. The plan that continues almost universally in use however is the original mode of carrying the rail upon the bottom of the chair, or upon a piece of hard wood placed on the bottom of the chair.

A form of chair has long been in general use throughout the West Cornwall Railway, which carries out the principle of suspending a double-headed rail in a very efficient and satisfactory manner, and is found to have an advantage in simplicity and economy of construction, and in freedom from jar or hardness of the road in travelling.

This Chair is shown in Figs. 1 to 3, Plate 76, and consists of two independent half-chairs or brackets, of nearly similar form, fitting close to the underside of the upper head of the rail, and extending down below the rail without any bottom to the chair underneath the rail. The chair is made high enough to raise the bottom of the rail 1-32nd inch clear above the sleeper, as seen in Fig. 2. The two halves of the chair are secured by a $1\frac{1}{16}$ inch bolt passed through the rail, with a nut on the inner side; the nut is held from turning by dropping into a recess in the chair, and the bolt is screwed up by the head. The bolts of these chairs are found to require tightening up a few times after first laying the rails, and they become then very secure, and give but little trouble afterwards by working loose. The two half-chairs are not exactly alike, and have the cheeks inclined so as to give the rail an inclination of 1 in 20 inwards.

The chair is secured to the sleeper by screwed spikes or fang bolts, and the spike hole through the inner half of the chair is slotted, as shown in the plan, Fig. 3, to allow that half of the chair to be drawn back sufficiently for taking out the rail, if required, without withdrawing the spike. The chair is prevented from shifting in regular work by the slot being blocked with a circular washer, which fits in a recess at the end of the slot, and is kept down by the head of the spike.

The writer believes that this chair was designed by Mr. Brunel in 1858, and was first used by him on the Vale of Neath Railway. It was also laid by him and Mr. Brereton on the Llynvi and Ogmore, the South Wales Mineral, and the Briton Ferry Dock Railways. It was adopted on the West Cornwall Railway in 1862, and by 1866 the whole of the line was relaid with these chairs, except on the viaducts where the longitudinal system is more suitable. The specimen chairs now exhibited were some of the first laid, and have been in use on the main line for eleven years.

There has now been fifteen years' experience of the working of these chairs, during which time they have undergone no apparent deterioration, and the writer has never heard of any accident having

happened through their failure. The first lot of chairs laid on the West Cornwall Railway in 1862 were not quite so high as they should have been, and allow the lower head of the rail to touch the sleeper; but a large number of these rails have now been turned, and in no case has the lower head been found to be injured. No instance has occurred of a sleeper breaking under the rail, nor has any indication been observed of a tendency in that direction. The result has been thoroughly satisfactory as regards durability, safety, and economy of maintenance.

The shortness of the leverage at which the strain acts upon the chair reduces materially the risk of fracture; and there is a striking difference in this respect in comparison with the large number of broken chairs that occur from driving the wood keys in the ordinary construction of chair. The division of the chair into two separate portions gives an elasticity to the support of the rail, which makes the road soft and easy for travelling; and this construction is free from the risk of a rail getting displaced by the loss or slackness of a key. The union between the rail, chair, and sleeper, is so good that there is no beating motion between them, and in the event of any movement consequent upon loose ballast the whole moves as one piece.

These chairs contain much less weight of metal than the ordinary form, as there is not any metal beneath the bottom of the rail, and no strength is required in the chair to resist the ordinary strain of keying. These chairs consequently weigh only 17½ lbs. each, instead of from 28 to 42 lbs., making the weight per mile only 29 tons instead of 69 tons, or a difference of 40 tons, which, after allowing for bolts in the one case and wedges in the other, gives a saving at present prices of £382 per mile of single line.

A specimen was exhibited of the bracket chairs which had been in use on the main line for eleven years, being some of the first that had been laid down on that line.

The President mentioned that the paper just read had been prepared for the recent Cornwall Meeting of the Institution, at which many of the Members had had the opportunity of seeing the chairs in use on the West Cornwall line. Unfortunately Mr. Sheriff was unable to attend the present meeting, but he had sent the specimen exhibited of the chair. There might be considerable doubt felt by some as to whether the construction now shown was free from objection; and he should be glad to hear opinions upon this subject.

Mr. C. E. Amos said that from a purely mechanical point of view the construction of the bracket chair appeared to him to be an advantageous one, and he thought it was calculated to realise all the advantages that were attributed to it. In regard to the circumstance mentioned in the paper, that the tie bolt uniting the two halves of the chair was screwed up by the head, while the nut was held from turning by fitting into a recess in the chair, he did not see how this was an advantage over the ordinary plan of turning the nut; for he thought, if there were any tendency to shake loose, the bolt was likely to get loose as easily when screwed up by the head as when tightened by turning the nut. Considering however that the whole was screwed up tight, metal to metal, he thought there was very little chance of its shaking loose or causing any trouble, whichever mode of screwing up was adopted.

Mr. W. E. Newton thought this simple construction of chair was calculated to achieve success, because a great many of the breakages in the ordinary construction of chair arose from the expansion of the wood keys by the absorption of moisture. It was well known that the force exerted by wood swelling through absorption of moisture was exceedingly great, so that it could be employed even for bursting masses of rock in quarrying operations. It was therefore not surprising to find that a great many of the ordinary solid cast-iron chairs had been burst by the expansion of the wood keys; and the bracket chair now described was evidently not only a much cheaper construction, but was also calculated, he considered, to obviate that difficulty.

The President observed that one point to be noticed with regard to this construction of chair was that the rail was perforated by a large hole at each chair; and though this would not be a serious objection with a rail having a rigid bearing on the bottom, as in the ordinary chairs, he thought it would be a considerable drawback in the present case of a suspended rail, by weakening the rail in its continuity. It was remarkable how much a rail was weakened by such a hole being made through it, especially a steel rail. Having had occasion lately to make some experiments on this subject, he had found that, while a sound steel rail laid across bearings 3 feet apart would bear repeated blows of a ton weight falling upon it from a height of 20 feet without giving way, a piece of the same rail laid across the same bearings with only an inch hole punched through the centre and midway between the supports broke with a single blow of a ton weight falling on it from only 6 feet height, showing how greatly the rail was weakened by the perforation. This seemed to indicate that chairs which did not involve the necessity of perforating the rail would be preferable. There were however many compensating advantages in the bracket chair now described, particularly the absence of any bursting pressure upon the chair; and the experience already gained of it was a considerable proof in its favour.

Mr. D. Halpin asked whether the President's experiments on the effect of perforating rails had been extended to the difference between drilled and punched holes, which was a question that had recently arisen in connection with rails used on the Metropolitan Railway.

The President replied that it had made hardly any difference in the strength of the rail whether the hole were punched or drilled; and he thought that would always be the case if the material was good and tough.

Mr. C. C. Walker considered it a very important fact which had been stated, that in good material the metal was not weakened more by punching than by drilling.

Mr. C. E. Amos said he entirely concurred in that statement; but he was surprised to hear that a steel rail was so much weakened as had been mentioned by simply perforating it with a small hole,

and he considered under the same conditions a good wrought-iron rail would hardly have been injured by the hole, and would not have been nearly so easily broken. It appeared to him there was yet much to be learnt in regard to the nature and properties of steel, notwithstanding the experience hitherto gained from its use, and the very numerous experiments made upon it. It seemed to be less reliable in strength than wrought iron, for he had seen some steel bars when tested give way at once without any alteration in section at the point of fracture, while others would only yield after having undergone considerable alteration, thus exhibiting a remarkable variation in strength in different makes of steel.

Mr. C. C. Walker mentioned that in some experiments he had lately made upon the breaking strain of cast-iron bars, of 2 inch by 1 inch section and supported upon bearings 3 feet apart, he had found that, while such a bar of the toughest and strongest cast iron would bear a dead weight of 32 or even 33 cwts. before breaking, yet the blow of a 21 lbs. hammer falling from a height of only 15 ins. or even 12 ins. would break it. On the other hand, another bar of a different quality of cast iron, which would bear a dead weight of only 23 or even only 21 cwts., required a blow from the same hammer falling 24 ins. or even 28 ins. to break it. This showed plainly that the cast iron which proved the strongest under the test of a dead weight, and was in such particular request for bridges and girders, was really often the weakest to withstand a blow; and cast iron which was weaker under a dead weight would require a much greater force of blow to break it. Moreover the iron that bore the greatest dead weight was not only broken by a lighter blow, but was broken into several pieces by the blow. It therefore appeared to him a great mistake to regard only the test of a dead weight for cast-iron structures that were required to resist a blow as well as a dead weight; and he considered the strength of the iron under a blow should also be taken into account.

Mr. C. E. Amos observed that an analogous case was that of earthenware, which would bear a considerable dead load, but if let fall would break readily. At Messrs. Maudslay's works he understood it had for many years past been the practice to select all

the cast iron employed there by casting a sample bar of given section and length, and laying it across bearings fixed for the purpose, and then dropping a given weight upon it from a given height; if the bar bore that blow without breaking, the iron was considered to be of the required strength.

Mr. D. Halpin suggested that in testing cast iron by the blows of a falling weight it would be desirable to agree upon some standard of comparison; and the best iron would then be that which bore the greatest number of blows of given force before breaking. Under a dead weight too, some bars might bear a very great load and then yield suddenly at last, while others would give way more gradually under a smaller load, showing a great difference as regarded the work done upon the iron in effecting its fracture.

The President considered it must not be concluded that steel was not a reliable material, on account of the great difference in the results in testing different bars. No doubt a bar of one sort of steel would break like a piece of pottery ware, while another of a different sort could not be broken by any number of blows, even though turned over and struck alternately upon opposite sides. But in order to understand why in one case a bar of steel broke and in another case did not break, and why a piece of steel which would bear one sort of strain would not stand another, it was necessary to take into consideration the chemical composition of the different kinds of steel. A bar of steel containing a considerable percentage of carbon would not stand a moderate blow from a falling hammer, but would stand a greater dead weight than a bar which would not break under the blow of the hammer; whilst on the other hand a bar that would resist the blow of the falling weight would not sustain so great a dead load. There was a difference between mild steel and wrought iron in this respect, namely that steel would bear a constant and gradual strain much better than iron, whereas iron would not give way under a sudden strain so readily as steel, particularly if the form were irregular in both cases. And this he thought was a necessary consequence of the homogeneous character of steel, owing to which, if a sudden strain came upon it, the weakest section at once received that strain entirely, there being

no fibres to take the strain one after another, and therefore if the strain were excessive the steel would give way by tearing like paper; whereas with wrought iron, although it might be distorted by a sudden strain, yet each fibre would not break at the same moment, and thus an iron bar would not be broken by a blow which would break a steel bar. It was this property of steel which rendered it wholly inapplicable for armour-plating; but it was no reproach to steel to say that under certain conditions it would break more readily than wrought iron, considering that under other conditions it bore much higher strains and was more reliable.

He moved a vote of thanks to Mr. Sheriff for his paper, which was passed.

The following paper was then read:—

ON TILGHMAN'S SAND-BLAST PROCESS, AND ITS APPLICATION FOR CUTTING STONE &c.

By Mr. WILLIAM E. NEWTON, of London.

In this process, which is the invention of Mr. B. C. Tilghman of Philadelphia, a jet of sand propelled at a high velocity by a steam or air blast is employed as a tool for cutting stone, and for producing ornamental carving on stone and other materials; and at a lower velocity of jet it is employed for grinding and ornamenting the surface of glass.

This new process in the arts is based upon the fact that when grains of sharp sand are driven with a high velocity against a hard surface such as glass, stone, slate, marble, wood, or iron, the surface is cut away more or less rapidly. The greater the pressure of the steam or air producing the jet, the higher is the velocity imparted to the grains of sand, and the more rapid and powerful their cutting effect upon the surface exposed to them. The term "sand" is employed to signify small grains or particles of any hard substance, having any degree of fineness, of which common quartz sand is a type.

At a high velocity of impact the grains of sand cut substances much harder than themselves. Corundum can thus be cut with quartz sand, and quartz rock can be cut by small lead shot; and sometimes iron sand composed of small globules of cast iron has been used. The hardest steel, chilled cast-iron, or other metal can be cut by a stream of quartz sand. Metallic surfaces can by this means be smoothed and cleaned from incrustation, in preparation for being tinned or otherwise coated; and the surfaces of dressed stone in buildings can thus be cleaned. By means of stencil plates, letters or designs can be engraved upon hard substances; also by varying

the shape, number, and direction of the jets of sand, and traversing them over the work, cuts or holes can be made of any shape, or size.

When sand of a brittle nature, such as quartz or emery, is very rapidly projected against a hard material, its grains are broken by the shock into fine powder, and the process can thus be used as a method of pulverising. Where a jet of water under heavy pressure is used, as in hydraulic mining, the addition of sand causes it to cut away hard and close-grained substances, upon which the water alone would have little or no effect. Pebbles or stones as large and heavy as can be rapidly projected by the jet of water have a penetrating and dislocating effect which assists the disintegrating and scouring action of the water.

Hitherto, in the use of sand for grinding or cutting, it has been applied either between two surfaces moved over each other under heavy pressure, so as to make a series of scratches, as in the ordinary cutting of stone and glass; or else in a solidified form, as in a grindstone or sand paper; and sometimes in a semifluid state, as when a substance is rubbed in a mass of sand. The peculiar feature of the Sand-Blast process, which distinguishes it from the other methods of cutting and grinding, is that each grain of sand acts by its own velocity and momentum like a bullet or projectile, and pulverises or indents the object it strikes. In consequence of this peculiarity of its action, some substances, which though comparatively soft are also tough or elastic and cannot therefore be pulverised by a blow, such as copper, lead, paper, wood, or india-rubber, are less rapidly cut and ground by the sand blast, particularly at moderate velocities, than much harder substances of a brittle nature, such as stone, glass, or porcelain. A peculiar advantage of the sand blast is that its action takes place with equal effect upon irregular surfaces and recesses hardly accessible to ordinary methods of working. Steam is generally found most convenient for the impelling blast, particularly for high velocities; but in some cases air is preferable. Steam of all pressures has been used up to more than 400 lbs. per square inch, and its efficiency has been found to increase with the pressure.

In Fig. 1, Plate 77, is shown a longitudinal section of the construction of jet apparatus employed in the process of cutting stone; and in Fig. 7, Plate 78, is shown the mode of its application. The sand is fed into a funnel A, Fig. 7, which is connected by a flexible pipe B with an iron or steel tube C, Fig. 1, of any convenient length and of about 1-6th inch bore. This sand tube is secured exactly in the centre of an iron or steel casing D, which forms the steam chamber. The annular space between is closed steam-tight at the back end; and at the front end or orifice the casing is shaped with a tubular neck, and brought to the same length as the sand tube C. The neck of the casing is bored out to a diameter of 0·26 inch for a length of about $\frac{1}{4}$ inch from its end, and for about $\frac{1}{2}$ inch length from the end the sand tube C is reduced to 0·23 inch external diameter, so as to leave a uniform annular opening of 0·015 inch in width, extending backwards for a length of about $\frac{1}{4}$ inch, and then enlarging gradually to the full diameter of the casing D; this annular passage forms the opening through which the steam blast issues. The casing or steam chamber is connected with the boiler by a flexible pipe E, so as to allow of the jet apparatus being turned and moved in any direction. A tube G, called the nozzle tube or gun, about $\frac{1}{3}$ inch bore and 6 inches long, made of wrought iron, steel, or chilled cast-iron, is fastened on the neck of the casing D by means of a set-screw. The end of the sand tube C is accurately adjusted and fixed in the centre of the steam aperture, so that the annular opening is everywhere of exactly the same width all round; and the nozzle tube G is adjusted so that its axis coincides with the axis of the steam jet issuing from the annular opening; the perfect accuracy of these adjustments is important. The bore of the nozzle tube G is adjusted by trial according to the size and pressure of the steam jet, so as to produce the amount of suction desired in the sand tube.

The sand used is sifted of even size, and should be clean, hard, sharp, and dry, so as to run regularly through a small hole without clogging. Sand which will pass through a sieve of 40 wires per inch and not through one of 48 wires is found to cut

faster than that which will pass through a sieve of 20 wires per inch and not through one of 30 wires. The steam should be perfectly dry, and when used at a distance from the boiler a steam separator should be added to free the steam from condensed water, and the pipes should be kept well wrapped.

In the working of the instrument, the steam when turned on issues with great velocity from the annular opening, and creates by suction a current of air through the sand tube. A valve in the bottom of the sand box H, Fig. 7, is now opened sufficiently to let a stream of sand of from one to two pints per minute fall into the funnel beneath, whence it passes down the sand pipe and is carried by the current of air through the sand tube and sucked into the jet of steam, by which it is driven through the nozzle tube at a high velocity, and finally strikes against the stone to be cut, the end of the nozzle being held at a distance of an inch or two from the stone. The shattered fragments of the sand and stone, partly in the state of very fine powder, escape sideways and backwards, together with the waste steam. A dull red light may be seen at the spot where the sand blast strikes the stone.

If the sand blast is kept directed steadily upon the same spot, a hole is gradually cut, the diameter of which at the surface is greater than that of the jet issuing from the nozzle; but the hole grows smaller and becomes conical as it penetrates deeper into the stone. This tendency to form a conical hole increases with the hardness of the stone, and diminishes as the pressure and velocity of the blast are increased. To make a hole or groove with parallel sides, the blast has to be inclined slightly towards each side alternately, the degree of inclination varying with the hardness of the stone and the pressure of the jet used. In cutting granite with a steam jet of about 300 lbs. pressure per square inch, an inclination of about 1 in 9 from the perpendicular will make the sides of the cut parallel; but with the same jet acting perpendicularly on rather soft burnt brick, without any inclination, the sides of the cut were almost parallel. Sufficient space must always be allowed for the escape of the waste steam and sand;

and consequently when a deep hole has to be cut, its diameter must be large enough to admit of this escape all round the blast pipe when advanced to nearly the bottom of the hole. By directing the blast pipe successively to all parts, a hole of any shape can be cut, either with parallel sides, or with the sides undercut so as to make a hole of larger diameter at the bottom than at the top; chambers for blasting powder can thus be excavated.

In cutting holes or grooves it is convenient to use a blast pipe bent just behind the annular jet to an angle of about 1 in 9, and to use a nozzle tube only about 2 inches long. By this means an inclined jet can be obtained in a comparatively narrow groove or hole, so that the main length of the blast pipe can be inserted parallel with the groove, while from the bent nozzle the sand blast issuing in an inclined jet makes a cut having one side parallel to the line of groove. By the bent blast-pipe with short nozzle-tube an inclined jet can thus be obtained in a narrower groove than if the pipe were straight, because in the latter case the groove would have to be wide enough to admit of the whole length of the blast pipe lying in it at the inclination required. In cutting long narrow grooves, a pair of parallel guide plates of iron or steel are added, about $1\frac{1}{2}$ inch wide and 3 inches long, as shown in Figs. 3 and 4, Plate 77, so as to form a prolongation of the nozzle tube G, the space between the plates being equal in breadth to the bore of the nozzle tube. The effect of these plates is to prevent the sand blast from spreading laterally, and thereby the edges and surface of the groove are made more even and regular. In dressing stone so as to produce a round surface, as in stone balusters, a narrow groove about $\frac{1}{2}$ inch deep is first cut, and then the overhanging edge is broken or split off, as shown in Fig. 8, Plate 78; the groove is then deepened and the new overhanging edge broken off, and so on; the successive relative positions of the nozzle tube are indicated by the dotted lines, the tube itself remaining stationary while the stone is rotated at intervals in the direction of the arrow. A curvilinear groove of any desired form can be obtained by giving a corresponding movement to the jet by means of a template. When the stone varies in hardness at

different parts, the blast must be kept directed upon the hard parts until they are worn down to the desired level; but it must be passed more quickly over softer parts, according as they are seen to be sufficiently cut. As most kinds of stone contain frequent alternations of hard and soft parts, constant care and attention have to be given to obtain an even surface. A sheet-iron guard or shield is arranged to protect the face and eyes of the workman from the rebounding sand; and a narrow slit in it enables him to watch and regulate the progress of the operation.

If the axis of the nozzle tube does not coincide accurately with that of the steam jet, the nozzle becomes rapidly cut away by the sand blast; and if any obstruction from dirt or scale chokes up one side of the annular opening of the steam jet, the sand blast will be distorted sideways, and will rapidly cut away the nozzle tube. Even under good conditions the sand blast gradually cuts away the nozzle tube, which has therefore to be examined continually, and renewed when required.

The quantity of stone cut by the sand blast is much greater when ample space is afforded for free escape of the expended sand and steam after they have struck the stone, than when the space is narrow and confined. When a rapid lateral traverse is given to the blast pipe or to the stone, so that the sand is constantly striking upon a fresh surface, a much greater cutting effect is produced than when the blast is kept directed upon one spot. In the latter case it appears that the expended sand rebounding from the stone interferes considerably with the fresh sand which is being projected against the stone; this interference is particularly evident when a hole is cut but little larger than the diameter of the sand jet. It has been noticed that when the sand blast is held at 4 or 5 inches distance from a stone a greater quantity is cut than when held at only 1 inch distance; also that when the sand blast is directed at an angle of from 30 to 45 degrees from the perpendicular a greater quantity is cut than when the same sand blast at the same distance is directed perpendicularly upon the stone. The explanation of these cases appears to be that the divergence of the sand blast spreads it over a wider surface of the stone, and also gives more

R 2

room for the waste to escape, thus avoiding interference with the sand in the jet. In cutting a narrow groove however, more progress is made by keeping the blast pipe directed square against the stone, and keeping the stone as close to the guide plates as its shape will permit; for although the total quantity of stone cut away may be less than at a greater distance, the effect is more concentrated and confined to the desired spot and direction. The quantity of sand used with a given steam jet may be considerably varied according to the effect desired to be produced. When a soft stone is to be cut over a wide surface, and there is consequently a free lateral escape, two or three times the quantity of sand used in the preceding cases can be employed; but where a hard stone is to be cut in a narrow groove, a small feed of sand produces a better result.

For quarrying stone or slate, or cutting into hard rock, as in driving tunnels, Fig. 5, Plate 78, deep grooves are required to be cut, as indicated by the dark lines, 6 feet deep or more and from 3 to 4 inches wide, so as to detach a block from the solid rock. To cut such grooves two or more sand-blast jets are combined, as shown in Figs. 6 and 7, and are set at the required slight inclination to each other for keeping the sides of the groove parallel throughout its depth. When two jets are arranged in this manner, Fig. 7, they cut two grooves with a projecting fin left between, which is easily broken away by a heavy tool, so that the nozzles can then be introduced within the groove to cut two fresh grooves at the bottom, leaving a fin to be broken off as before; and so on until a groove of sufficient depth has been made. This plan answers very well with slate, sandstone, and other soft stone; but for harder rocks three jets are used, as shown in Fig. 6, where two fins are left to be broken away. Another mode of working the sand blast, for cutting a wide groove, is to mount the jet pipes in such a manner that they describe a series of small circles as they travel along; in this way the groove is cut to a uniform depth without leaving any fin to be broken away afterwards. In order to quarry slate, or building stone which is required in rectangular

blocks, a series of vertical and horizontal grooves may be cut in the face of the rock to any convenient depth, and then the blocks may be broken off the solid rock by driving wedges into the grooves, so as to dispense with blasting the rock, and avoid the danger of shattering it. This is a very important advantage also in tunnelling, as the ordinary process of blasting frequently shatters the rock so much that it becomes necessary to construct an artificial roof for the purpose of preventing the shattered portions from falling down and causing accidents by blocking up the way.

The principal points to be attended to, in order to obtain the best results in economy of power and time in working with the sand blast, are, first to get an impelling jet of great velocity; second, to feed the sand regularly, and in such a manner that it shall acquire as nearly as possible the velocity of the impelling jet; third, to direct the jet of sand upon the desired spot, without wasting its force in wearing away the nozzle tube; and fourth, to provide free escape for the expended steam and sand, so as to avoid interference.

Where only a small quantity of material is to be cut or ground away by the sand blast from the surface of a hard substance, and where only a moderate velocity of jet is required, a blast of air produced by a rotary fan is found to be convenient. This method is used for grinding or depolishing glass, china, or pottery, either over their entire surfaces or for the production of ornamental designs. In engraving designs, air is more convenient than steam for the impelling jet, because with air the sand keeps dry, and rebounds, leaving the pattern clear; but with steam the sand becomes damp, and is apt to adhere to the fine lines and corners and clog them. The sand being fed into the air jet by falling from a column of sufficient height is carried along by the air in a tube or close trunk, and directed upon the glass, which is held or moved opposite the mouth of the trunk; the sand jet thus cuts or stars the surface of the glass wherever it strikes it.

The arrangement of apparatus for grinding or depolishing flat glass is shown in the vertical sections, Figs. 9 and 10, Plates 79 and

80. The air current from the fan, having a pressure of about 4 inches of water, is brought in by a trunk K of about 2 square feet sectional area, and descends through the narrow vertical slot J of about 1 inch width, from the bottom of which it issues with a velocity proportioned to its pressure. Into the upper end of the air slot J the sand is evenly fed from the sand box H above, by means of the sand slot L of about $\frac{1}{2}$ inch width, the lower end of which is closed by an iron plate perforated with holes about $\frac{1}{4}$ inch diameter and $\frac{1}{2}$ inch apart, so as to supply from 15 to 20 cubic inches of sand per minute for each square inch of cross section of the air slot J. In passing down the air slot the sand acquires a velocity proportioned to that of the air jet, and strikes upon the plates of glass, which are made to traverse across underneath the mouth of the slot at about 1 inch below its orifice. The plates of glass are carried upon a set of india-rubber belts N, which travel at the rate of about 8 inches per minute, so that each part of the glass is exposed to the action of the sand blast for about 6 or 8 seconds. After striking the glass the air and sand pass away at the sides into the large settling chamber M below, where they lose their velocity, and the sand settles to the bottom, while the air escapes at the aperture O or returns to the fan. To diminish the escape of dust and sand into the external atmosphere, india-rubber flaps P P are provided, Fig. 10, which close with a slight elastic pressure upon the glass passing through. The pressure of the blast holds the sheets of glass down upon the belts carrying them. The sand from the bottom of the settling chamber M is raised by an elevator R into the sand box H at top, and is used over again repeatedly until it becomes too fine.

For cutting a design upon glass, the covering stencil plate must be of a strength and durability proportioned to the thickness to be cut away. Toughness and elasticity and the absence of brittleness appear to be the qualities needed for resisting the cutting action of the sand. India-rubber, particularly when vulcanised, possesses the desired properties in an eminent degree; parchment and parchment-paper also possess considerable durability. Stencil plates made of paper or thread are

rendered more durable by covering them with a tough or elastic varnish. A design can either be drawn on the glass with the paint thickly applied by the brush ; or the glass can be covered all over with paint, and the design cut through the protecting coat when dry. A layer of wax resists a sand blast having a pressure of 1 inch of water impelling sand which has passed through a sieve of 50 wires per inch. A film of bichromatised gelatine produced by photographic processes is capable of resisting the action of a blast of the same fine sand during a sufficient time to allow of the exposed portions of the glass being cut by the sand blast; and photographic pictures have been engraved by this means. The finer the sand used and the lower the pressure of the blast, the finer is the grain of the depolished surface, and the weaker and more delicate may be the texture of the covering substances used to produce the design. Any of the processes by which a design can be produced or transferred in a sufficiently tough medium may be used to prepare a surface for being engraved by the sand blast. Many natural objects, such as plants, leaves, &c., which can be fastened flat upon a surface, offer sufficient resistance to a blast of fine sand to admit of their outline being thus engraved. When wood is subjected to a sand blast of moderate velocity, the softer and more brittle portions are more rapidly and deeply cut away than the others, and the grain of the wood and the hard lines and knots are thus brought out in relief. When the sand blast at a moderate velocity is directed upon a metallic surface, it removes but little of the metal, but the grains of sand make innumerable small indentations in the surface, and produce a frosted or deadened appearance; and by means of stencil plates any design can thus be engraved on metallic surfaces.

Mr. Newton showed a number of specimens illustrating the application of the sand-blast process in grooving and cutting marble, sandstone, granite, and other materials, and in depolishing and ornamenting glass. He pointed out that a special peculiarity of the process was that not only could many kinds of work which were ordinarily done by hand be produced by it automatically and at a very trifling cost, but other things could also be done which could not otherwise be produced at all at anything like a reasonable cost. An example of this kind was a specimen exhibited of an inscription cut in granite with raised polished letters; the cost of this by hand work would have been very great, but it was done by the sand-blast process with great facility and expedition. The mode of executing this work was by first polishing the surface of the stone, and then cementing upon it metal letters forming the intended inscription, and subjecting the whole to the sand-blast; the surface of the stone was by that means cut away uniformly wherever it was not protected by the metal letters; and on removing the metal templates the inscription was left in relief, with letters polished on the face and finished with fine sharp edges. The operation was effected with a single steam jet moved backwards and forwards over the work at a rate of about 20 ft. per minute, and the stone was traversed slowly at the same time in a transverse direction, until the jet had passed once over the whole surface; the cutting of the specimen shown, 10 ins. square and 3-16ths inch depth of cut, required only 8 minutes with a pressure of 60 lbs. steam, and it was done with the steam jet exhibited, with $\frac{5}{8}$ inch bore of tube.

The pierced ornamental marble panel exhibited was cut at two operations, by placing a thin iron template on one face of the marble, and sinking the pattern half through its thickness by means of the sand-blast; the marble was then turned over and the template fitted upon the other face, exactly corresponding in position with the first side, and then subjected to the sand-blast again until cut completely through. A perforated design was thus formed, having the edges all chamfered regularly from each face, on account of the tapering form of the holes cut by the sand-blast; the specimen shown, of about half a square foot area and $\frac{3}{4}$ inch

thickness, was completed in 30 minutes with a steam jet of 50 lbs. pressure, and a similar specimen cut in sandstone was completed in only 10 minutes. Another specimen showed a similar design cut in glass to the depth of $\frac{1}{2}$ inch.

When the material operated upon was not of uniform hardness, as in the case of granite (which was an agglomeration of substances of different degrees of hardness), the bottom of the hollows was not cut level, and the harder portions, such as the quartz crystals, were left projecting, and these had to be dressed down by hand to finish the work; but in uniform materials, such as marble and slate, the whole was left neatly finished by the sand-blast process. Sunk panels in wood carving were readily produced by this process, but the time required was about twice as long in oak as in marble, on account of the wood having a certain amount of elasticity, which softened the effect of the impact of the grains of sand. In operating upon oak, the greater hardness of the grain of the wood caused the bottom of the hollows to be left uneven; but with boxwood the work was left with a level surface, and the specimens exhibited showed a beautiful finish.

By using a higher pressure of steam jet, the hardest substances could be cut, as shown by the hole cut in the specimen exhibited of corundum, a mineral twice as hard as granite; and even hardened steel could be cut, as shown by the specimen of a file 5-16ths inch thick, having a slot through it 5 inches long and $\frac{3}{8}$ inch wide, which was cut in about 30 minutes, by means of a jet of 60 lbs. steam.

The PRESIDENT observed that, as the intensity of action of the sand-blast depended on the surface operated upon being unyielding to the impact of the grains of sand, hard steel might be expected to be cut away more readily than soft steel.

Mr. NEWTON thought soft steel would be found hard enough to get the full effect of the sand, and would be cut easier than hard steel. He remarked that in the application of the sand-blast it was necessary to prevent the action being impeded by the particles of sand interfering with one another. The effect of this interference was strikingly shown in a specimen of granite exhibited,

containing four holes of the same diameter but of different depths; the first hole of $\frac{1}{4}$ inch depth was cut in 1 minute, the second of $\frac{1}{3}$ inch depth in 2 minutes, the third of $\frac{1}{2}$ inch depth in 3 minutes, and the fourth only a little deeper took 5 minutes: this was an illustration of the rapid diminution that took place in the rate of cutting as the depth increased, on account of the greater interference amongst the grains of sand. In cutting a groove the grains of sand were confined by the sides, and the groove became very narrow at the bottom on account of their action being checked by the interference; but in working over a flat face there was a free escape for the grains of sand on all sides, and the efficiency of the sand-blast was consequently much greater in that case. When cutting a groove in granite the quantity of material removed was about $1\frac{1}{4}$ cubic inch per minute, but when acting on a more extensive surface the rate of work was fully double that amount. In cutting deep grooves it was necessary to make the groove 4 ins. wide, in order to allow the jet pipes to enter the groove; but in the case of cutting very deep grooves for the purpose of quarrying or tunnelling, where they would probably be wanted as much as 8 ft. depth, a moveable jet was preferable, either revolving in a small circle whilst traversing along the groove, or travelling backwards and forwards across the groove, so as to change its position rapidly, and thereby lessen the interference of the grains of sand with one another, and avoid leaving in the groove a fin which would require to be broken off afterwards.

Mr. Z. Lloyd asked to what extent the sand-blast could be applied to slate quarrying, and whether the relative cost of working could be given per ton of material got, as compared with the ordinary process; also whether air or steam blast was proposed for such a purpose, and how the jet would be carried forward on the face of the work.

Mr. Newton said the sand-blast had not yet been practically applied to quarrying or tunnelling; but from the results of trials upon blocks of slate, it was anticipated that it would not be necessary to make any holes for blasting, but that by cutting a groove along the bottom and a cross groove at each end a large

rectangular block could be wedged off of any desired length, and in a form suitable for splitting up without waste. The sand-blast would be applied either by a steam jet or by compressed air, as might be most eligible for the application; and he did not think there would be any practical difficulty in conveying the power wherever required over the working face. A very coarse sand would be used, which would act with great force, and cut away very fast. If a certain amount of work was already done in a given time when cutting grooves in the trial blocks, he thought it might be expected the greater amount of work required in applying the sand-blast to quarrying or tunnelling would also be done in some proportionately longer time; and that the result would be much better than with the present unsatisfactory plan of boring a number of holes and blasting, which shattered the material badly.

Mr. Z. Lloyd enquired what depth of groove had been cut already with the sand-blast.

Mr. Newton replied that grooves had been cut in slate to a depth of as much as 8 ins. in 20 minutes, but there was not any practical limit to the depth that could be cut, so long as the jet could be got in and manipulated in the groove; if a groove could be cut of 8 ins. depth, he was not aware of any reason for doubting the practicability of cutting one of several times the depth. Practical difficulties would however no doubt arise, such as occurred in the ordinary process, when all the circumstances of quarrying and tunnelling came to be met.

Mr. A. Paget asked what pressure of jet was supposed to be required for applying the sand-blast to quarrying.

Mr. Newton said that would depend upon the hardness of the material, but for slate he thought a pressure of 50 lbs. would be quite sufficient.

Mr. A. Paget thought that if 50 lbs. steam was enough it would be quite practicable to convey this by ordinary india-rubber tubing wherever required for working the sand-blast; and though there was not yet any practical information about the application of the process to quarrying, there was a fair prospect of its success in carving stone with great saving of cost.

Mr. C. E. Amos said he had seen the sand-blast in operation both for cutting stone and for ornamenting glass, and had been very much struck with the rapidity and powerful effect of the process in cutting stone. He had seen a piece of granite subjected to the jet, and in a few minutes it was completely cut like the specimens exhibited; and the ornamenting of glass was done with the greatest facility. The great success of the applications already made of the process suggested the probability of further usefulness, by extending the application to many other purposes than those at first thought of, and amongst others to quarrying and tunnelling; but there was not the means of forming any reliable estimate of the cost of working for quarrying, because until actually put in practice it was impossible to tell what contingencies might arise. He had himself designed a machine for tunnelling some years ago for Major Beaumont, whose idea was to cut a groove round a block and also a central hole, and then break the piece out; a number of cutters were fixed round a circular revolving head about 5 ft. diameter, which cut a groove $1\frac{1}{4}$ inch wide and 2 feet deep, the centre hole being also 2 feet deep and $1\frac{1}{4}$ inch diameter. This machine had been found useful; but now the question arose whether in the case of refractory stone the new process of the sand-blast might not be cheaper and more expeditious for the purpose than other machines. He was acquainted with the working of large slate quarries, as at Penrhyn, where the work was carried on by a succession of galleries or steps in the face of the quarry, each about 40 feet rise; and the practice was to bore holes in the floor or tread of each gallery and blast the rock forwards, and then work up the material into the various forms required, whilst the blasting was proceeded with further on. Whether the sand-blast process could be applied efficiently for working on that plan might be a question, but the mode of working might probably be modified to suit the process.

Mr. A. Paget asked how long the metal templates lasted which were used in cutting patterns upon stone; or how many pieces of stone could be cut with one template before it became worn out.

Mr. Newton said that with a sheet-iron template $\frac{1}{4}$ inch thick 100 pieces of marble could be cut to a depth of 3-16ths inch; and a

hard cast-iron template $\frac{1}{4}$ inch thick served for cutting 100 to 150 pieces, whereby it became worn down to $\frac{1}{8}$ inch thickness.

Mr. C. E. Amos said he had seen glass ornamented by using a piece of lace as a template, and the lace did not show the least injury with the moderate pressure of jet used for working on glass.

Mr. W. C. Aitken enquired whether the process was in regular operation at any works, and if so to what extent it had been carried out.

Mr. Newton replied that Messrs. Chance were now putting up machinery at their works near Birmingham, for the grinding of glass and for ornamenting enamelled glass by this process. The process had not yet been introduced into this country longer than about five months, and the first time of putting it in operation here was at the International Exhibition in London, where three of the machines were regularly at work. In one of these, marble and sandstone were cut with a steam jet of 50 lbs. pressure; and the second was the machine for depolishing sheet glass, which was shown in the drawings exhibited, and was working with an air jet of $\frac{1}{3}$ lb. pressure. The other machine was a small one for ornamenting glass by engraving small patterns and monograms; and by this machine any tumblers and wine glasses or other glass could be readily marked with a monogram in only 3 or 4 seconds each.

Mr. W. C. Aitken observed that some specimens were shown of Britannia metal ornamented by the sand-blast process, and giving a very uniform dead surface; and he enquired whether it had been applied to preparing the surface of lithographic stones, as there would be an evident advantage if the ordinary slow process of preparation could be superseded. The sand-blast process seemed to offer so many advantages for different practical applications, he felt surprised it was not yet in use practically in this country, having been brought out two years ago in America. In ornamental metal work this process might perhaps be made to take the place of the minute and complicated process of "saw-piercing," and it would be a much quicker process than eating the metal away with acid. Fluoric

acid was extensively used in glass works for etching ornamental designs on glass; he thought the sand-blast process would prove much cheaper as well as much quicker for that purpose.

Mr. Newton said that the process had been successfully applied to preparing the surface of lithographic stones, and also to graining the surface of zinc plates for similar purposes; and according to the coarseness or fineness of the sand used, a coarse or fine grain could be produced with certainty on the plate. Engravings from photographs had also been produced upon glass by the sand-blast, of which a number of specimens were exhibited, showing that the minutest shades were reproduced with the utmost softness. In the fluoric acid process for etching on glass, the cost averaged 15*d.* to 18*d.* per square foot of surface operated on, but with the sand-blast the same work could be done for only 1*d.* per foot, besides the cost of the stencil plate, and the latter would be a very small cost for such patterns as were likely to be used with acid. With the sand-blast however the most beautiful designs could be executed with the same facility as the commonest ground glass, and a paper stencil plate was sufficiently durable in that case; but in producing a fluoric acid design, the outline was first etched in with the acid, and the whole had then to be ground in.

Mr. W. C. Aitken remarked that the action of the sand abraded the glass, leaving a dead frosted surface where acted upon, which would make it inapplicable for several purposes, but the action of the fluoric acid left the surface comparatively bright; in the sand process, if the surface had to be brightened afterwards, that extra cost would seriously reduce the advantage in economy. If however the ornamentation had to be done in relievo instead of intaglio, the use of the sand-blast would prove a great advantage for removing the superfluous glass. With respect to ornamenting or cutting monograms on table glass, the only difficulty he saw was that the sand left a rough surface which would not easily be kept clean; etching with fluoric acid left a comparatively bright surface, though neither so bright nor so smooth as glass when cut or engraved by the ordinary process.

Mr. W. Maltby (from Messrs. Chance) said he had examined with a magnifying glass the work done on glass by the sand-blast and that by fluoric acid, and found the edges of the pattern were sharper and clearer with the sand-blast process. He asked whether after the machine had done working there was not a running down of the sand out of the hopper above into the bottom receptacle.

Mr. Newton replied that there was not any waste in practice; the supply of sand was shut off by a slide when the action was not going on.

Mr. C. C. Walker asked about the abrasion of the nozzle tube with the steam jet, whether the sand-blast did not wear out the tube so as to require frequent renewal.

Mr. Newton said the tube usually lasted only a couple of days, but it was renewed very readily and cheaply; it was a chilled cast-iron tube slipped upon the end of the steam jet, and cost only about 4*d.* to renew. If the tube however was not accurately made, and was out of centre in the bore, it became worn quite oval, and required renewal sooner.

Mr. D. Halpin enquired whether trouble was experienced from water in the steam jet, and whether superheated steam had been tried for keeping the sand-blast dry.

Mr. Newton replied that it was necessary for the steam to be dry, especially for fine work, as any moisture would cause the hollows of the work to get clogged up with the fine particles of sand; but he did not think it had been found necessary to use superheated steam for the purpose.

The President thought the very interesting and novel process of the sand-blast admitted of application to a variety of useful purposes, and very probably to a greater extent than had at present been contemplated in the way of ornamenting surfaces, and as an aid to the architect in producing designs on stone. Whether it would be applicable to tunnelling on a large scale, experience alone could show; but at present there was quite application enough in the purposes of ornamentation, for which it was clearly well suited. Its action was evidently based on the principle that a blow between

perfectly hard substances was infinite in amount; and consequently whenever two hard substances were brought into collision, even with moderate velocity, the one or the other broke up, and the less yielding they were the greater must be the destructive effect. That consideration had led him to enquire whether a hard steel file would not be cut through in a shorter time than a bar of soft steel; and he should be glad if a comparative experiment were made to ascertain that point.

He moved a vote of thanks to Mr. Newton, which was passed, for his paper and the very interesting collection of specimens with which it was illustrated.

The following paper was then read:—

DESCRIPTION OF A WROUGHT-IRON CONSTRUCTION OF OBSERVATORY, FOR MAINTAINING EQUALITY OF INTERNAL AND EXTERNAL TEMPERATURE.

By Mr. CHARLES CLEMENT WALKER, of Donnington.

The construction of an Observatory is required to be such as to afford complete protection to the telescope when not in use, and at the same time to maintain it in perfect condition for use whenever desired; and the latter point is of special importance in this country, in consequence of the opportunities for astronomical observation being so few in comparison with the numerous nights that are unfavourable for the purpose. In order to obtain the correct performance of the telescope, it is requisite for the temperature of the surrounding air inside the observatory to be the same as that of the external air, so that no local currents of air may be set up when the doors are put open for observation; because the accuracy of definition of the telescope is seriously impaired when the light suffers irregular refraction through currents of air of different densities, such as occur when a difference of temperature exists in the surrounding air. This is especially the case with reflecting telescopes, on account of the air being free to move within the open tube of the instrument; and reflecting telescopes are so much affected by this cause that they can seldom be used satisfactorily except in the open air; and the difficulty experienced in constructing observatories free from air currents has checked the use of reflecting telescopes, notwithstanding their great advantage in moderate cost as compared with the very great cost of refracting telescopes of corresponding size.

The desideratum is therefore to obtain the convenience and advantage of an observatory, in a building that will keep the telescope in the same condition as if in the open air. For this purpose it is required that the walls of the building should offer so

little obstruction to the passage of heat through them that the temperature inside may follow at once all changes in the temperature of the external air ; and to attain this object, it is necessary not only that the walls should be good conductors so as to transmit the heat rapidly, but also that the whole amount of heat stored up in the mass of the walls should be so small as to produce little effect in retarding the corresponding change of temperature inside the building, whenever a change takes place in the temperature of the external air. A thorough and continuous communication with the external air by free ventilation is also requisite.

The special point is to secure this equilibrium of temperature in the air during the evening and night, the time when the telescope is generally wanted for use ; so that when the doors are opened for using the telescope, there may be an entire freedom from disturbing currents of air of different temperatures and densities. The great difficulty has been to get rid of the day's heat in preparation for the night's use of the observatory ; and in the ordinary construction with thick walls of slowly conducting materials, several hours are found to elapse before equilibrium of temperature is restored after any long exposure to the direct rays of the sun in the daytime, owing not only to the large amount of heat taken up by the material of the building, which has to be all dispersed, but also to the slow rate of transmission of the heat through the walls. Even a construction of thin boards or canvas requires a considerable time to restore equilibrium of temperature after a hot day, when a difference of temperature of 40° Fahr. between day and night is of common occurrence.

As an attempt to remove this difficulty, a Wrought-Iron Observatory has been constructed by the writer, in which his idea has been to employ no material in the building except a good conductor of heat, and to obtain sufficient strength with a very small thickness and total mass of material. This building, which is shown in Figs. 1 to 5, Plates 81 to 83, is constructed entirely of wrought iron, with thin sides and top, and light angle-iron framing riveted together. In Plates 81 and 82 are shown an elevation and plan

of the observatory when closed and when opened; and in Plate 83 is a vertical section to a larger scale. This observatory has proved thoroughly successful in maintaining uniformity of temperature with the external air; and in the evenings and nights (when this is specially required) the internal and external temperatures are found to be exactly the same or within $\frac{1}{2}^{\circ}$, although the heating effect of the previous mid-day sun may have been very great.

In the usual construction of observatory the top only is made to revolve for giving the telescope a view in all directions, and the axis of the telescope is then required to be above the level of the side walls in order to obtain horizon views; but this involves the inconvenience of using high steps to reach the eye-piece, and requires an increased height of dome. The writer determined therefore in the present observatory to make the whole building turn round; and this allowed the adoption of an octagon shape as more convenient for construction in wrought iron, and preferable to a circular form in the general external appearance and finish of such a building.

The telescope A, Plate 83, for which it is constructed, is a $10\frac{1}{4}$ inch reflector, with silvered glass speculum of 6 feet focal length, and equatorially mounted; the pillar is bolted down upon a stone and brick pier B, about 2 feet square and 5 feet deep, which is kept quite free and isolated from the joists and boards of the floor. A clear space of $\frac{1}{2}$ inch is left all round the pier, and the isolation is so complete that not the least vibration is perceived in the telescope even with a high power, from any amount of shaking of the floor. The circular rail C upon which the building revolves is fixed down upon a wood cill on a ring of brickwork, and is cast in segments with the ends tongued together. This rail has teeth cast upon the outer side, 1 inch pitch, as shown to a larger scale in Figs. 8 and 9, Plate 84, making a fixed circular rack of $11\frac{1}{2}$ feet diameter, into which gears a pinion D of $2\frac{3}{4}$ inches diameter, for turning the building round by a hand winch E.

The building is an octagon, 12 feet diameter inside, with sides 7 feet high, and a sloping roof flat in the centre, as shown in Plates 81 and 82; and it is constructed with a framing of $2\frac{1}{2}$ inch

angle-iron at the bottom and the angles of the sides, covered with sheet iron of 18 wire-gauge and flush-riveted. Each side is in four sheets, with a flat bar riveted over their junction, forming them into neat panels; and two opposite sides are made to open as a pair of doors. For zenith views with the telescope, a pair of doors in the flat top are opened, giving a range of 23° on each side of the zenith; two pairs of doors in the slope of the roof give a view to 60° from the zenith on each side, and the main side doors give the view to the horizon. The roof doors are readily opened from the inside by quadrant-shaped handles, which have holes and pins to keep them open or closed; and the whole or any portion may be opened as desired, so as to expose the observer to as little external cold as possible. In order to get the rain water off the flat centre of the roof, a small cover slide on the sloping roof doors is pushed up when these are closed, as shown in Fig. 7, Plate 84, and is drawn down when they are opened, that the sloping doors may then clear the centre ones.

The sides of the observatory have an opening of 4 inches width all round under the eaves, as shown in Fig. 5; and an opening $\frac{1}{2}$ inch wide is left all round at the bottom beyond the edge of the fixed floor, giving clearance for revolving the observatory; by these means free ventilation is constantly maintained. No rain can enter at these openings; and it is only required to provide flaps for closing the upper opening in the case of snow, to prevent its drifting in. The roof doors are protected from entrance of rain by a tongue and cover strip along their meeting edges, as shown at F in Fig. 6, Plate 84. The building is moved round upon the circular rail by a pair of bevil wheels G, Fig. 8, driving the pinion D that gears into the circular rack; the whole is carried on 4 inch flanged wheels H fixed upon brackets on the bottom angle-iron, and can be turned round with the greatest ease by the hand winch E. When the observatory is fully open for observing through the whole range from zenith to horizon, as shown in Plate 82, the three top bars K which cross the opening are taken down, being made removable for the purpose; and as the building is thereby cut in half at that point, any tendency to spread out is prevented by first putting a

connecting bar L with a tightening screw across the door opening, below the horizon level of the telescope.

The result of two and a half years' working of this observatory has been completely satisfactory. However rapid or sudden the changes of external temperature may be, the internal temperature is found to follow so quickly that the difference does not exceed 2°, and is generally found to be less than 1°, at the time of opening the observatory for use. However great may have been the extent of heating of the building by exposure to the sun during the day, the internal temperature in the evening is found to be practically the same as that of the external air, with the building still closed; so that when opened for use, the telescope is found already in the same condition as if standing in the open air, and does not require any interval for cooling before being in proper condition for use.

The following are two examples of the results with a falling temperature in the outside air, the inside temperature being taken by a thermometer hanging free in the centre of the observatory:—

Time	3·0 p.m.	7·5 p.m.	8·5 p.m.	11·0 p.m.
Inside temperature	71°	49°	47°	45°
Outside temperature	—	47½°	45°	45°

Time	3·10 p.m.	6·15 p.m.	7·45 p.m.	8·45 p.m.	9·45 p.m.
Inside temperature	76°	61°	58°	59°	57½°
Outside temperature	—	60½°	58°	59°	57½°

These examples show that, even with so great a fall of temperature as 26° from day to night, an equilibrium of temperature between the internal and external air is maintained throughout the evening within 2°. These results are confirmed by numerous observations made under various circumstances, and indicating a difference of temperature generally of less than 1°; and also showing how closely the observatory follows the temperature of the external air at the critical time of sunset.

The following is an example of a rising temperature in the outside air by a change in the night after sunset, and shows an equilibrium maintained throughout:—

Time	7·0 p.m.	10·0 p.m.	7·45 a.m.
Inside temperature	45°	47°	54°
Outside temperature	45°	47°	54°

In all the above cases the thermometer for measuring the temperature of the external air was hanging free, away from any building, and protected from the heat of the direct rays when the sun was shining; but when exposed to the sun the walls of the observatory become heated above the temperature of the external air, and the internal air is consequently raised in temperature, as shown in the following example:—

Time	9·30 a.m.	1·0 p.m.	2·30 p.m.
Inside temperature	66°	73°	72°
Outside exposed thermometer	70°	81°	75°
Outside temperature in shade	55°	62°	63°

The outside exposed thermometer was upon the wall of the observatory, and showed an excess of temperature of 12° to 19° above the external air in the shade, with an excess of 9° to 11° in the temperature of the internal over the external air.

A building of slowly conducting material, such as brick, stone, or wood, has an apparent advantage in such cases, in retarding this heating effect upon the internal air, in consequence of the transmission of heat through the walls being slower. The rapidity of transmission in the case of the iron observatory is not however any practical disadvantage, for as the occasions of using the telescope in the daytime are for observation of the sun, the building can then be thrown open, protection from the weather being not then required; and the heating of the internal air by a closed building is thus obviated. The rapidity of transmission of heat through the walls of the iron observatory is on the contrary the point of special value in its construction, as this provides for its rapid cooling down after the withdrawal of the sun's direct rays; the excess of heat is thus quickly dissipated, and the equilibrium of temperature restored between the inside and outside air.

As a test of the rapidity of transfer of the heat and recovery of equilibrium of temperature, it may be mentioned that when the observatory is exposed to the direct rays of the sun, and then

suddenly screened by a cloud passing over, causing a fall of temperature in the external exposed thermometer, the temperature inside begins to follow in about three minutes, falling as rapidly as 4° in five minutes; and when the external temperature continues uniform for as long as ten minutes, the internal thermometer comes within less than 1° of the external air. Whatever small differences of temperature occur between the internal and the external air seem due to the constant variations in the temperature of the external air. An illustration of the effect produced by the use of slow conducting material in retarding the rate of cooling has been afforded by a wood drawer containing books within the observatory, which is found to retain a portion of the mid-day heat so long, that in the evening the temperature within the drawer is 10° higher than the air within the building, whilst the latter has at the time the same temperature as the external air. Also in the morning, in a rising temperature after a cold night, the air in the observatory is assimilated so rapidly to the open air, that the heavy mass of the telescope pillar, though iron, becomes covered with moisture, from not having followed the rise of temperature of the air; while the observatory and telescope continue perfectly dry.

The President observed that the object of this wrought-iron construction of observatory was not to maintain the same temperature inside as outside during the daytime while the sun was shining, which might be impracticable; but to have a building which after sunset would rapidly assume the temperature of the external air, so that when required for use the telescope should be in the same condition as if standing in the open air.

Mr. F. Bird enquired whether after a severe frost the walls of the observatory kept dry, and whether the silvered mirror of the telescope ever became coated with dew at such a time. In other

observatories there was generally a great deposition of moisture upon the walls and instrument after frosty weather.

Mr. Walker replied that, whenever the external air was so thick with moisture that all outside was covered with dew, the interior of the observatory was of course affected in the same manner as if in the open air, when standing open for use. The deposition of moisture within the building when closed could be prevented to a large extent by closing the shutters all round the eaves; this however was not intended to be done ordinarily, because the object was merely to screen the observer from the weather, while securing the same temperature and state of atmosphere within the building as in the open air. The moisture coming in with the external air did not interfere at all with the observations, nor was there ever more moisture inside than outside. After a continued severe frost, in observatories constructed of brick, stone, or other non-conducting materials, the thickness of the walls stored up so much cold, and it took so long a time for the returning warmth of the weather to penetrate them, that the moisture in the air was condensed upon them to such an extent that they streamed with water, and kept the telescope in the same condition, often for several days, till equilibrium of temperature was restored. He knew of cases where the water deposited had to be baled up from the floor, and also poured off the face of the speculum. Nothing of the kind ever happened with the iron observatory, the walls of which stored up no cold, because they were so thin; and whatever alteration took place in the external air, the internal air partook of it at once, and consequently no moisture was condensed; and since it had been constructed, the telescope had never been hindered from immediate use by deposition of moisture, even after the most severe weather. In the morning, with a rising temperature after a cold night, while the walls of the observatory remained perfectly dry, he had known the iron pillar of the telescope become covered with moisture when the sun began to shine, in consequence of the rapid rise of temperature in the air, which was followed much more slowly by the mass of iron in the pillar. In the same way the metal of the telescope holding

the speculum followed the rise of temperature more slowly than the air in the building, and continued at first 3° or 4° colder than the air; there was consequently sometimes a slight film of moisture upon the surface of the speculum for a few minutes in the morning when the sun began to shine, but this disappeared as soon as ever the speculum was exposed to the sun. In the daytime, whilst exposed to the direct rays of the sun, the walls of the building, like all other solid opaque objects, became of course heated to a much higher temperature than the surrounding transparent air; and consequently the air within the building then became heated considerably above the outside air, to the extent of as much as 11° higher in the observations recorded in the paper; but it would be noticed that at that time there had been no less a difference than 19° between the external temperature in the shade and in the sun.

Mr. C. E. Amos remarked that the internal temperature of 73° in that instance was nearly a mean between the two external temperatures of 62° in the shade and 81° in the sunshine.

The President enquired whether the exposed thermometer was placed against a wall exposed to the sun, or was hung exposed to the sun at a distance from any solid object; this would materially affect the result of the observation.

Mr. Walker replied that the exposed thermometer was hung about an inch from the iron wall of the observatory, directly facing the sun. The temperature of the internal air was seen to follow regularly that of the external air, continuing about a mean between the external temperatures in the sun and in the shade.

Mr. F. Bird asked what was about the cost of an observatory like that described in the paper.

Mr. Walker replied that at the present time the cost would probably be about £75, but it would depend upon the price of iron. A wooden building might be a little less expensive, but considering the efficiency and general advantages of the iron construction he thought it was preferable. The octagonal shape was not at all objectionable in appearance, and was more convenient for an iron structure than a circular form, which also he thought would not have looked so well.

The PRESIDENT enquired what was the weight of the revolving portion of the observatory, and how much heavier it was than the revolving dome in an ordinary building for a telescope of the same size.

Mr. WALKER said the revolving weight was about 15 or 16 cwts., which was about double the weight of the revolving dome in an ordinary observatory of that size. The building could be pushed round by hand, but was rotated with the greatest readiness by the hand winch as being so much easier and more convenient.

The PRESIDENT enquired what was the reason for mounting the observatory upon cylindrical flanged wheels, which involved the friction of the flanges against the rail, as well as the friction arising from the cylindrical wheels having to run in a circle; conical wheels appeared a more correct form for travelling round the circular rail.

Mr. WALKER said that conical wheels required a fixed centre to revolve round, in order to keep their path, and this was inadmissible in an observatory. The flanged wheels kept the revolving building truly central, and the rail being rounded on the top, the surface of contact of the cylindrical wheels was so small that very little resistance was offered to their running in a circle, the flanges also being bevilled so as to touch the rail to the least extent possible. The whole resistance to revolving the observatory was so small that a child could turn it round easily by means of the winch handle.

Mr. A. PAGET remarked that, as the revolving portion of the observatory could not be allowed to touch the centre pillar, a set of vertical guide rollers would have been required for preventing conical wheels from running off the rail, if flanges had not been used, which would have been an increase of expense without an equivalent advantage; and he thought the friction of the flanged wheels, though of course greater than the friction of the conical wheels, must be so slight as to be practically immaterial when a child could turn the observatory round with the flanged wheels.

The PRESIDENT considered the iron construction of observatory now described was an interesting application of mechanical

contrivance to a scientific purpose, and judiciously carried out. He moved a vote of thanks to Mr. Walker for his paper, which was passed.

The Meeting then terminated.
